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COMMITTEE PRINT

SATELLITE TECHNOLOGY AND WORLD FOOD SECURITY

REPORT

PREPARED FOR THE

SELECT COMMITTEE ON HUNGER
U.S. HOUSE OF REPRESENTATIVES

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LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
SELECT COMMITTEE ON HUNGER,
Washington, DC.

To Members of the Select Committee on Hunger:

I am pleased to transmit to committee members the enclosed report, "Satellite Technology and World Food Security." I believe this report prepared by the Science Policy Research Division, the Environment and Natural Resources Policy Division and the Office of Senior Specialists of the Congressional Research Service will be a valuable resource for committee members and others concerned with the struggle against hunger and malnutrition. Because of the coordination involved in its preparation and the broad scope of the report, the space and environmental communities will also find it extremely useful.

The report covers the activities of the United States, foreign nations and international agencies concerned with agricultural assessment, monitoring of the environment and natural resources, and with development and applications of satellite monitoring systems. A separate section describes in detail the U.S. and international satellite systems currently in operation and planned for the future. It concludes with a discussion of policy issues concerning space monitoring applications to agriculture and food security.

Sincerely,

TONY P. HALL, *Chairman.*

LETTER OF SUBMITTAL

THE LIBRARY OF CONGRESS,
CONGRESSIONAL RESEARCH SERVICE,
Washington, DC, October 12, 1989.

Hon. TONY P. HALL,
Chairman, Select Committee on Hunger, U.S. House of Representatives, Washington, DC.

DEAR MR. CHAIRMAN: I am pleased to submit a study prepared by the Congressional Research Service on Satellite Technology and World Food Security. This study was requested by your predecessor as chairman, Hon. Mickey Leland, shortly before his tragic death in Ethiopia while en route to a camp to inspect conditions of Ethiopian refugees.

Satellite technology offers increasingly sophisticated capacity for monitoring and evaluating the uses and conditions of the Earth's natural resources. U.S. Federal agencies and international organizations are making extensive use of this technology in their systems for assessing world food supply and demand, managing natural resources, and planning agricultural and economic development. The future and cost of remote sensing satellites, agency capacity to use remote sensing data, international cooperation in satellite applications, and the ability of developing countries to use satellite technology affect the prospects for more extensive use of this valuable tool.

This report was prepared by Patricia E. Humphlett, Analyst in Aerospace and Telecommunications Systems, Charles E. Hanrahan, Senior Specialist in Agricultural Policy, Susan R. Fletcher, Specialist in Natural Resources Policy, and Marcia S. Smith, Specialist in Aerospace Policy.

I hope that you and the committee will find this report useful in your continuing efforts to identify more effective ways of responding to the interrelated problems of world hunger, poverty, and environmental deterioration.

Sincerely,

JOSEPH E. ROSS, *Director.*

PREFACE

The interrelationships between hunger, poverty, and environmental conditions have become increasingly clear. As the world's population continues to grow rapidly, and is projected by the United Nations to reach perhaps 14 billion in the next century, the need to understand the Earth's capacity to produce food becomes a key element in attempts to assure world food security. In this context, the need to better understand the conditions of the world's resource base is critical. Data available from satellite technology offer important opportunities to achieve an ongoing capacity to assess agricultural and environmental conditions, manage natural resources, and contribute to meeting food needs throughout the world.

Accordingly, the late Hon. Mickey Leland, Chairman of the House Select Committee on Hunger, requested a report by the Congressional Research Service (CRS) on the satellite systems that generate data relevant to world food security issues, including weather, land remote sensing and ocean sensing. Focusing on the applications of such data to food security by agencies of the United States and international organizations within and outside the United Nations, Chairman Leland requested CRS to discuss availability of the data from U.S. and foreign satellites to the world community and identify both existing satellites systems and those planned for the 1990's.

Identification of policy issues of concern to the Committee was also requested, including such matters as the future of the LANDSAT system, whether food security issues are given adequate consideration in planning new monitoring and research efforts, and guaranteeing timely access to data.

The resulting report covers the activities of the United States, foreign nations, and international agencies concerned with agricultural assessment, monitoring of relevant environmental and natural resource considerations, and with development and applications of satellite monitoring systems. A separate section describes in detail the U.S. and international satellite systems currently in operation and planned for the future. The report concludes with a discussion of policy issues concerning space monitoring applications to agriculture and food security.

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SATELLITE TECHNOLOGY AND WORLD FOOD SECURITY

SUMMARY

Congress and the public have evidenced increasing concern about widespread hunger and poverty in the world and the deterioration of the Earth's environment. There is a growing awareness about the links between such phenomena as the persistence of hunger and poverty, the loss of natural resources and long-run environmental impacts of global warming.

World food security, defined as the ability of the Earth to feed growing populations, requires attention to both agriculture and the environment in a global setting. Agriculture and the environment can be monitored from the unique vantage point of Earth-orbiting satellites. Remote sensing technologies can increase our capacity to identify and solve these interrelated problems and thus contribute to enhancing global food security.

Remote sensing data gathered by satellites are being used in combination with ground and statistical data to assess agricultural and environmental conditions. Weather and land remote sensing satellites developed by NASA are being used by NOAA, USDA, AID, and international organizations like FAO and WMO to predict and respond to droughts, floods, and locust infestations in the United States and Africa. Remote sensing is also contributing to efforts to better manage natural resources. Foreign satellites systems are also being used separately or in coordination with U.S. systems.

Realizing the potential of satellite technologies to contribute to world food security will depend upon how a number of important issues are resolved. The most critical are whether current satellite capabilities will be continued; whether future development of more comprehensive satellite systems and development of data applications will occur; whether user agencies will have the capacity to take advantage of remote sensing data; whether the interagency and international cooperation and coordination critical to the comprehensive monitoring for understanding earth systems can be achieved; and whether developing countries with severe food security and environmental problems will be able to build the capacity to benefit from satellite technology and applications.

Remote sensing is an important tool. The ability to forecast drought in Africa did not prevent starvation in Ethiopia. However, satellite monitoring of deforestation in Brazil has contributed to the Brazilian Government's changes in policy to attempt to reduce burning of the forests. Ultimately, food security and environmental problems are political issues that can only be solved by governments. Obtaining data to clarify the problem is a vital first step, however.

INTRODUCTION

Congress and the general public have evidenced increasing concern about widespread hunger and poverty in the world and deterioration of the Earth's environment. There is growing awareness about the links between such phenomena as the persistence of hunger and poverty throughout the world, the loss of natural resources, and global warming.[1]

World food security, which can be defined broadly as the ability of the Earth to feed adequately its growing number of people, requires attention to both agriculture and the environment in a global setting. Both agricultural and environmental conditions can be monitored from the unique vantage point of Earth orbiting satellites. Many have suggested that the use of remote sensing technologies in monitoring agricultural and environmental conditions will increase our capacity to solve the interrelated problems of hunger, poverty, and environmental deterioration and contribute to enhancing global food security. Public concern about global climate change and other environmental impacts of human activities has been translated into plans and proposals for expanding satellite monitoring activities at the national and international levels.

Recent measurements of changes in the Earth's atmosphere that are attributed to human causes have heightened the awareness that natural systems may be altered by activities occurring in distant regions. Understanding the functions of Earth's natural systems, the kinds of changes taking place in them, identifying the causes of these changes, and understanding their impacts on practical concerns, such as agricultural production, have become increasingly urgent.

The essential beginning point for such understanding is the gathering of data on current natural systems. Human ability to do such data collection has been powerfully augmented by the increasing sophistication of satellite systems. Proposals for more comprehensive coverage of the Earth by satellite monitoring are under development, as discussed in this report.

It is clear that applications of satellite technology can greatly extend our ability to detect and understand changes in the natural resource base, vegetative cover, soil conditions, and other conditions critical to world food security. The question remains, however, whether this ability will be exercised, and to be successful, several types of activities must be integrated. The appropriate satellite technology must be in place on a continuous basis. This means technology that makes use of the most advanced kind of sensors to detect changes on the Earth, and the data collected, must provide continuous coverage over time, in order to allow trend detection. A data analysis and management capability must exist in order to make satellite and ground-based data meaningful. Data analysis will need to be tailored to meet the needs of users, or user agencies. These applications of data—defining what is to be measured—must be planned and designed by the user agencies, which means that

[1] The report of the World Commission on Environment and Development, the Brundtland report, is among the most recent discussions of the interrelatedness of environmental, poverty, and food problems. World Commission on Environment and Development. Our Common Future. Oxford, Oxford University Press, 1987.

appropriate technical expertise must be available in the user agencies.

This report describes the extent to which U.S. Government agencies, foreign nations, and international organizations use satellite technologies in their programs for monitoring and making assessments of agricultural and environmental conditions.[2] Such programs can contribute to world food security by improving information about world supply and demand for food or by providing the basis for responding to food emergencies caused by drought, floods, or famine. Some U.S. and international agencies use remote sensing data in programs to improve the management of natural resources or to devise long term development plans. Whether in monitoring, resource management programs, or development planning, satellite remote sensing data must always be combined with ground-based, aerial and statistical data. The report concludes with a discussion of issues raised in considering the role of satellite technology in contributing to world food security.

[2] We omit discussion of U.S. and European military and intelligence satellites.

U.S. GOVERNMENT AGENCIES INVOLVED IN AGRICULTURAL AND ENVIRONMENTAL ASSESSMENT

U.S. Remote-Sensing Capabilities

Remote sensing satellites gather data which, when combined with data gathered on the ground, have many valuable applications. Weather satellites gather information about rainfall and the health of vegetation that is used to monitor drought and predict crop yields. Crop yield estimates allow the United States to respond to expected food shortages in some areas of the world and to changing crop prices in other areas.

Weather and land remote sensing satellites also can collect data to inventory types of vegetation, including forests and wetlands, both of which play a vital role in the general ecological system. The loss of tropical rain forests in Brazil, for example, has been linked to the greenhouse effect and to the decreased population of song birds in North America. The decrease in wetlands in North America may decrease populations of many birds, which in turn allows insect populations to increase, causing greater damage and crop loss to farmers.

For the purpose of monitoring agricultural and environmental conditions, U.S. scientists and analysts primarily use data from the AVHRR (Advanced, Very High Resolution Radiometer) sensor on U.S. civilian polar orbiting weather satellites and from LANDSAT, the land remote sensing satellite system. AVHRR data can produce a vegetation index over large areas while LANDSAT's sensors provide more detail on smaller regions. Other satellites produce data on the oceans, atmosphere, and land.

U.S. weather satellites were developed primarily to monitor and measure weather and weather-related phenomena. The United States continues to improve its weather satellites to provide storm warnings and weather forecasts. The weather satellites also produce data that can provide valuable information on crop production and crop health, and amount of rainfall and temperatures which affect crops. The AVHRR sensor on U.S. polar orbiting weather satellites provides information from which scientists create a vegetation index, which describes the type of vegetation and its health and from which they can estimate crop production. In addition, the AVHRR data have been used by NASA to analyze the destruction of tropical rain forests in Brazil and other environmental concerns.

LANDSAT provides valuable information on the Earth's land masses, and in much greater detail than that provided by the weather satellites. (LANDSAT's troubled history and uncertain future are discussed below).

AVHRR *v.* LANDSAT DATA

Data from the NOAA AVHRR sensor are widely used when a scientist wants to cover a large area and does not require detailed data about small regions. The nominal costs involved in acquiring AVHRR data are another plus. According to one expert," For mapping and monitoring the vegetation of large areas when resolution is not a primary consideration but coverage and costare, AVHRR is becoming the method of choice (over LANDSAT)." [3] Other advantages include: the price per unit of AVHRR is about 0.1 percent of the price per unit of data from LANDSAT's multi-spectral scanner (MSS) and the thematic mapper (TM).

AVHRR has a wide field of view so it can image large areas simultaneously. One AVHRR image is spatially equal to 100 LANDSAT images and the wide field of view is good for characterization of subunits within a region.[4] Because AVHRR covers the entire globe each day, there is much less interruption of data collection because of cloud cover. LANDSAT's orbit takes it over any one location on Earth every 16 days, so that if an area is cloud covered on 1 day, it is 16 days until there is a second chance to get the data for that location.

LANDSAT data can be useful to study an area in detail. Often, a combination of data is used or LANDSAT data are used to confirm or refine preliminary studies that used AVHRR data. Examples include:

- LANDSAT's thematic mapper data (TM) compared over time can be used to discriminate and identify the specific cause of stress to vegetation, allowing scientists not only to track the decline of forests but to determine why they are declining—because of insects, drought, disease, and/or pollution. Scientists generally need intensive ground assessment in conjunction with satellite data.[5]
- Scientists found TM data to be 20 percent more accurate when making detailed maps of forest classes, although MSS data were 90 percent accurate in delineating healthy forests from insect damaged forests.[6]
- TM data, with better resolution, are needed to study specific ecosystems.[7] [The MSS has 80-meter resolution; the TM has 30-meter resolution.]
- In a study of coastal wetlands, which are a highly productive buffer zone and help to maintain the quality of coastal environments, MSS data were not sufficient unless supplemented with aerial photography. TM and SPOT (the French satellite) data, however, were good enough to use alone for biomass and productivity estimates.[8]

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[3] Greegor Jr., David H. Ecology from Space. BioScience. July/August 1986, p. 431.

While a weather satellite provides pictures of a part of a continent, LANDSAT focuses in on an area roughly the size of a football field or smaller. LANDSAT measures sunlight as it is reflected off of the Earth in different spectral bands. Scientists have learned that a particular reflectance reveals information about features such as vegetation, minerals, or water in each scene. Thus, LANDSAT can provide a wealth of information for a small area, including: the type of crop, the health of the crop, the need for increased irrigation or pest control, the size of wetlands, the loss of forest areas due to development, the amount of sediment in a stream, and much more.

The general public probably knows LANDSAT images best as false color photographs or images taken from space. While these images are one product of LANDSAT data, many scientists find greater use in the digital products which they can manipulate with computers to extract greater, more detailed information and which they can overlay on other digital data gathered from a region.

LANDSAT data can be used for a variety of purposes including monitoring food crop conditions, looking for oil and mineral deposits, or assessing the effects of pollution on the Earth. Two Government projects, LACIE (Large Area Crop Inventory Experiment) and AgRISTARS (Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing) coordinated research and analysis of U.S. crop production using LANDSAT data. These programs are discussed below.

The National Aeronautics and Space Administration (NASA) has traditionally been responsible for research and development of civilian satellite technologies. As such, NASA develops new technologies and applications, but generally does not have responsibility for operational programs. Operational systems are turned over either to the private sector or another Government agency. Thus, although NASA developed both the weather satellites and LANDSAT, and continues to contribute to remote sensing research, it does not operate either system. It does continue to use data from these satellites in its research on satellite data applications, but like any user, must buy the data.

From a world food security perspective, the three U.S. Government agencies that make extensive use of satellite applications and data are the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce, the U.S. Department of Agriculture (USDA), and the Agency for International Development (AID). NOAA is both a user and producer of satellite data, since it is the agency that operates the weather satellites. The international organizations with programs that affect world food security are two United Nations agencies: the Food and Agricul-

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[4] Roller, Norman E.G. and John E. Colwell. Coarse-resolution Satellite Data for Ecological Surveys. BioScience. July/August 1986, p. 468.

[5] Rock, B.N., et. al. Remote Detection of Forest Damage. BioScience. July/August 1986, p. 439.

[6] Williams, Darrell L. and Ross F. Nelson. Use of Remotely Sensed Data for Assessing Forest Stand Conditions in the Eastern United States. IEEE Transaction on Geoscience and Remote Sensing. January 1986, p. 130.

[7] Ustin, Susan L., et. al. Thematic Mapper Studies of Semiarid Shrub Communities. Bio- Science. July/August 1986, p. 446.

[8] Hardisky, M.A., et. al. Remote Sensing of Coastal Wetlands. BioScience. July/August 1986, p. 453.

ture Organization (FAO) and the World Meteorological Organization (WMO). The United Nations Environment Programme (UNEP) also plays a role in satellite monitoring. These international organizations use remote sensing data gathered not only by U.S.-launched satellites, but also satellites developed and maintained by the European Space Agency, France, Japan, the Soviet Union, and other countries.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) carries out research and development related to the Nation's civilian space programs. It is responsible for development of satellite systems and also development of applications and scientific analysis of data. However, once a system becomes operational, NASA ordinarily transfers it to another agency for operations, or to the private sector.

For this reason, NASA does not operate ongoing data collection systems such as the LANDSAT program; LANDSAT was transferred first to NOAA for operation, and then to the private sector. However, in its Office of Space Science and Applications (OSSA), NASA scientists are "responsible for NASA's efforts to understand * * * the integrated functioning of the Earth. The Office conducts space application activities, such as remote sensing of the Earth * * *"[9] OSSA utilizes spacecraft, rockets, balloons, aircraft and ground-based research to conduct its programs.

In its office of Space Science and Applications, NASA has an Earth Science and Applications Division which carries out developmental data analysis programs on selected worldwide environmental and natural resource conditions. Much of the agriculture and related research is done within the Terrestrial Ecosystems Program. In developing applications of remote sensing technology, NASA has used satellite monitoring data to analyze relative soil moisture worldwide which allows some desertification trends to be identified in vulnerable areas, such as Africa's Sahel. Another development of applications has made NASA a key source of information on deforestation in Brazil's Amazon Basin. Using weather satellite data, fires in the Amazon basin have been tracked over the past several years, and estimates of vegetative cover have been made, based on surface temperature and vegetation index. This information has played a key role in raising public awareness.

In developing these applications, NASA is using data collected by satellites now operated by other agencies or the private sector. NASA's research program in these cases is a computer analysis activity to extract deforestation or desertification interpretations from the satellite data, coupled with ground-based observation to validate the interpretation. The current emphasis is on a long-term data analysis monitoring activity, demonstrating how AVHRR satellite data can be used to monitor deforestation, desertification, soil moisture, and other land surface factors. This is done by comparing the AVHRR data with analysis of vegetation from other data and

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[9] National Archives and Records Administration, Office of the Federal Register. The U.S. Government Manual 1987-88. U.S. Govt. Print. Off., Washington, D.C., p. 606.

information. In addition to comparisons with data gathered on the ground—often called "ground truth"—the AVHRR data are compared with data from other satellites. The data from LANDSAT and SPOT (the French satellite) are the main satellite data being used for comparison, checking whether the analysis of AVHRR data coincides with results from these satellites that have much finer spatial resolution. Scientists involved in this research report considerable difficulty obtaining the comparative information, due to the high cost of buying the LANDSAT and SPOT data.

Although data are collected every day for all land areas of the Earth, the analysis of such data is complicated and time-intensive. Therefore, information from such satellite coverage is available only for areas of high research interest.

In its commercialization program, NASA carries out some applied work on agricultural systems through contracts to outside parties who share the cost of developing applications. One example is a contract to monitor potato yield in specific areas of the United States using LANDSAT data. Such activities are intended to develop, demonstrate, and implement the commercial usefulness of satellite data.

Another NASA program produced a series of data on the oceans that relates to food production from fisheries operations. NASA launched Nimbus-7 in 1978, and it was in operation through 1986. It used an instrument to measure ocean productivity called the Coastal Zone Color Scanner (CZCS). The data from the CZCS identified areas with a high concentration of phytoplankton, and when compared with fish catches in these areas, higher catches of albacore were reported. The application of such data, after they are analyzed for appropriate correlations with concentrations of edible ocean species, could be relevant to monitoring areas appropriate for fishing, as well as identifying areas where over-fishing has been a problem.

A recent NASA-managed interagency and international program under the auspices of ISLSCP (International Satellite Land Surface Climatology Project, sponsored by WMO, UNEP, ICSU, and other agencies) demonstrated the ability to apply concentrations of data sets from different sources to an area in Kansas, revealing "land surface properties" relevant to wheat production. This project is one example of the way in which NASA or other national space agencies may play a key role in international satellite monitoring applications.

MISSION TO PLANET EARTH

NASA has taken the lead in planning a coordinated, interagency effort to study the Earth and its natural systems called "Mission to Planet Earth" (MTPE). According to NASA, the goals of the program are "to understand the Earth as a system, and to determine those processes that contribute to our environmental balance, as well as those that may result in change." [10] By putting multiple sensors on one platform and deploying multiple platforms, scientists could receive and study a vast array of data simultaneously

[10] NASA. Earth Observing System, 1989 Reference Handbook. May 1989, p. 2.

measuring all aspects of the Earth's environment in order to better understand the highly interactive nature of the oceans, atmosphere, lands, and biosphere. Once scientists understand the processes which control the global environment, they can then begin to determine what impact human activities are having on the environment, and on critical natural resources.

The interagency aspects of Mission to Planet Earth are critical to its success, according to those involved in planning it. A large number of Earth-based monitoring stations would be necessary, as well as a greatly enlarged data analysis capability not only in NASA, but in other participating agencies. Key agencies include the National Science Foundation (NSF), NOAA, the U.S. Geological Survey, and many other potential participants.

International participation is an essential part of the MTPE, and it will be planned in conjunction with the International Geosphere-Biosphere Programme. The United States, Japan, and the European Space Agency (ESA) would provide polar orbiting platforms for the initial phase of the program, augmented by satellites in other orbits in the future, according to current plans. Surface-based stations on land and in the oceans would be contributed by a number of other nations.

The costs involved in the various elements of MTPE will be significant. Estimates call for expenditures of $15 to $30 billion over 15 to 20 years for the United States alone. At present, U.S. agencies other than NASA have not begun planning to factor these costs into their budgets.

NASA emphasizes that MTPE is currently a conceptual study, and that it has begun advanced studies on only one element of it, the Earth Observing System (EOS), a polar orbiting platform. At present, the first budget requests for planning and designing the system are being prepared for the fiscal year 1991 budget request. It is still unclear what specific instruments will be included in the initial EOS design.

MTPE would provide a greatly enhanced capability to measure land, climate and atmospheric systems critical to agricultural production. A question remains as to whether the funding needed to accomplish the comprehensive goals of MTPE will be available.

National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA), in the Department of Commerce, has responsibility for operating civilian weather satellites and for developing and using applications of weather satellite technology. Combining imagery from its polar-orbiting and geostationary weather satellites with surface weather information, NOAA can make agro-climatic assessments that provide early warnings of crop failure.[11] NOAA uses information on solar radiation, temperature ranges, precipitation, and vegetation indices to assess crop conditions. Within NOAA these

[11] This discussion of NOAA's role in monitoring and forecasting is based on Joan C. Hock, Monitoring Environmental Resources through NOAA's Polar Orbiting Satellites, ITC Journal, 1984-4, pp. 263-68 and Use of NOAA Climatic Impact Assessment Technology by Countries of the Sahel and Horn Regions of Africa for Operational Crop Monitoring and Range Management, PASA NO. BOF-00000-P-5099-00, AID, July 1, 1985.

assessments are made by the Assessment and Information Services Center (AISC) of NOAA's National Environmental Satellite, Data, and Information Service (NESDIS).

NOAA has participated in interagency research projects, among them AgRISTARS (see below), designed to develop and refine the use of remote sensing data for monitoring agricultural conditions. NOAA and USDA maintain a Joint Agricultural Weather Facility (also discussed below) for the purpose of monitoring the effects of weather conditions on U.S. and world agricultural production.

In 1985, NOAA provided AID with crop condition assessments for countries in the Caribbean Basin, Africa, South and Southeast Asia, and Central and South America. NOAA made its information available in a number of forms—a monthly climate impact assessment with weekly updates, early warning assessment cables sent to U.S. overseas missions, and special assessments on request by AID. NOAA has been involved in AID's Famine Early Warning System (see below) and has conducted training programs in satellite applications for both AID and developing country personnel.

As the above examples illustrate, NOAA's role in using satellite technology in relation to food security issues is carried out largely in cooperation with the USDA or AID. For this reason, detailed discussion of NOAA's remote sensing activities for assessing agricultural and environmental conditions is integrated into the discussion of USDA and AID programs which follows.

U.S. Department of Agriculture

The U.S. Department of Agriculture (USDA) uses remote sensing data in order to meet two broad objectives: assessments of U.S. and world agricultural supply and demand conditions, and resource management.

The U.S. Department of Agriculture is the main U.S. Government agency with responsibilities for assessing U.S. and global agricultural conditions that affect world food security. To monitor, forecast, and report on world food supply and demand conditions, USDA maintains an unrivaled national and global system for developing, using and reporting data and information on world agriculture.

USDA monitors agricultural and environmental conditions worldwide as part of its overall program of assessing agricultural supply and demand conditions. In practice, USDA gives priority to countries and regions of the world that are major commercial producers and exporters of agricultural commodities. Despite the overall priority given to foreign commercial agriculture, however, USDA, as one of the two main U.S. Government agencies with responsibility for administering the U.S. foreign food aid programs, does carry out monitoring and forecasting for areas of the world that are most prone to droughts, food shortages, and famine conditions.[12]

The USDA national and global information systems are designed to meet the informational needs of such client groups as farmers,

[12] The Agency for International Development (AID) shares with USDA the administration of U.S. foreign food aid programs.

businesses, consumers, exporters and others in the private sector, as well as the needs of policy makers and program administrators within USDA or in other Government agencies. For example, many farmers use USDA forecasts of prices or foreign crop conditions as a partial basis for determining the area to plant for the next season's crop or to make marketing decisions. USDA program administrators use information on domestic and foreign crop supplies in determining how much land should be taken out of production (set-asides) in order to balance supply and demand for agricultural commodities or to decide the nature or scale of market development or export credit programs. USDA and AID develop and use information on food supplies in developing countries to make decisions about foreign food aid programs.

Increasingly, USDA agencies make use of data gathered by remote sensing satellites for monitoring agricultural and environmental conditions in the United States and around the world. These data are combined with data from conventional sources—sample surveys, crop reports, market and price reports, reports from USDA's overseas staff—in making assessments and forecasts. Within USDA, there are four main organizational units or agencies involved in monitoring and forecasting world food supply and demand conditions. These are the Foreign Agricultural Service (FAS), the Economic Research Service (ERS), the National Agricultural Statistical Service (NASS), and the World Agricultural Outlook Board (WAOB).

USDA also uses remote sensing data to meet resource management objectives. The principal agencies involved in this resource management function are the Agricultural Research Service (ARS), the Soil Conservation Service (SCS), the Forest Service (FS), and the Agricultural Stabilization and Conservation Service (ASCS).

FOREIGN AGRICULTURAL SERVICE

The Foreign Agricultural Service (FAS) maintains a worldwide intelligence and reporting program to develop and disseminate information on world agricultural production and trade. The mainstay of FAS is the reporting by agricultural counselors and attaches in 75 posts throughout the world covering 110 countries. FAS analysts in Washington use the information gathered by attaches to develop estimates of current food and agricultural production and to forecast export potential for specific U.S. agricultural commodities or food products.

Gathering intelligence and reporting on agricultural and food supply conditions around the world is only one of the missions of FAS. Moreover, this information mission is geared primarily to support other FAS missions such as expanding foreign markets for U.S. agricultural products or administering agricultural export programs, including Public Law 83-480, the Food for Peace Program which provides for the sale of agricultural commodities on a long-term credit basis and the donation of agricultural commodities to foreign governments, private voluntary organizations, and the World Food Program. The information that FAS generates is also used in the formulation and coordination of overall U.S. Government agricultural trade policy.

Since the early 1970's, FAS has come to rely more heavily on computer-aided analysis of satellite, meteorological, and related data in making its assessments of foreign crop conditions and expected production and trade. The main unit within FAS that uses satellite data is the Foreign Crop Condition Assessment Division (FCCAD). Using LANDSAT and AVHRR data, FCCAD makes both quantitative and qualitative assessments of foreign crop conditions. FAS credits remote sensing with significantly improving the accuracy of crop estimates in the USSR, China, Australia, Brazil, and Argentina. Satellite imagery has been particularly important in making estimates of Soviet crops because of the lack of other reliable data on Soviet agriculture.

Beginning in 1981, FAS set up a high speed telecommunications network which allows FAS staff at foreign locations to create and transmit scheduled commodity reports to Washington. This system, the Global Economic Data Exchange System (GEDES), now provides over 75 percent of scheduled commodity reports to Washington. GEDES-generated information in summary form is also placed daily on a public access electronic network, thus giving same-day information to private sector users of the information.

FAS makes its data and analysis of world commodity production and trade available to the public in regularly published reports.

ECONOMIC RESEARCH SERVICE

The Economic Research Service (ERS) is another organizational unit within USDA that is part of USDA's global food and agricultural information system. ERS is the agency primarily responsible for economic research and analysis of factors underlying supply and demand for agricultural commodities and food products both domestically and internationally. ERS monitors domestic and foreign agricultural and economic activity and makes short-term and long-term forecasts of food and agricultural supply and demand. Within ERS, the Commodity Economics and the Agriculture and Trade Analysis Divisions analyze foreign food supply and demand conditions. The work of these divisions focuses on research and analysis of economic relationships that influence food and agricultural production, consumption, prices and trade in and among the countries of the world. The Agriculture and Trade Analysis Division prepares the annual report assessing world food production and needs that is mandated by Congress in Public Law 83-480.[13]

ERS does not have its own operational analytical capability to use directly satellite imagery in making its assessments of foreign crop conditions. Instead, in making estimates of foreign crop supplies, ERS uses the assessments prepared by the Foreign Crop Condition Assessment Division of FAS as well as the foreign weather information provided by the Joint (USDA-NOAA) Agricultural Weather Facility (discussed below).

In contrast to FAS analysts who make estimates of foreign agricultural supplies, ERS analysts also make estimates of the global demand for agricultural commodities and food products. Included

[13] This report entitled, World Food Needs and Availabilities, is mandated in section 408b of Public Law 83-480, the Agricultural Trade Development and Assistance Act of 1954.

in ERS estimates of demand are estimates of food aid needed by people in low-income developing countries. ERS uses data on income and population from U.S., international and individual country sources in making its assessments of foreign demand. In addition, ERS uses information on export earnings and foreign exchange reserves in making assessments of the capacity of countries to finance imports of agricultural commodities and food products.

Satellite data are less useful in demand assessment than in crop condition and supply prospects assessments. However, ERS does use computer technology, including microcomputers, in its manipulation of large data sets on global and country supply and demand for agricultural commodities and food products.

ERS assessments of world, U.S. and foreign country agricultural conditions are made available regularly in published form as well as via public access computer networks.

NATIONAL AGRICULTURAL STATISTICAL SERVICE

The primary responsibilities of the National Agricultural Statistical Service (NASS) are to develop and disseminate national and State agricultural statistics and to conduct statistical research. One of NASS's main contributions to USDA's global food information system, aside from its basic data on U.S. agriculture, is the research it has done to develop methods for using satellite data in making crop supply estimates. The research projects, discussed here, relied on LANDSAT and AVHRR data in combination with ground and statistical data gathered by more conventional means.

The two main research projects were the Large Area Crop Inventory Experiment (LACIE) and the Agricultural Resources Inventory Surveys Through Aerospace Remote Sensing research project (AgRISTARS). In the LACIE project, NASS developed and evaluated procedures using satellite imagery to monitor growing conditions for wheat on a worldwide basis and to relate data acquired through remote sensing to crop production variability.

The promising results of LACIE led to AgRISTARS, which was to provide production estimates of all major grains, not just wheat. NASA, NOAA, the Department of the Interior, and AID as an observer, worked with NASS on AgRISTARS from 1980 to 1986. The program had eight components: (1) early warning crop condition assessment, (2) inventory technology development, (3) yield model development, (4) soil moisture, (5) domestic crops and land cover, (6) renewable resources, (7) conservation and pollution, and (8) supporting research.

AgRISTARS allowed scientists to make significant progress in several fields of research, including: monitoring soil moisture, soil water modeling, models to assess better crop growth and crop yield, and development of forest inventories. The early warning and crop condition assessment project of AgRISTARS developed crop stress indicator models and led to the extensive use of NOAA's AVHRR data to assess crop conditions. Crop stress information can be used both to identify a problem area for treatment and to estimate crop production. Soil moisture assessment could be useful to allow farmers to irrigate only where needed and save on water and energy. Soil moisture also plays an important role in crop production esti-

mates in the United States and worldwide. AgRISTARS also developed land-cover inventories, land-use change estimates, resource information for forest management and planning, and an ability to measure disturbances and changes in forest and rangelands. The program also demonstrated the ability to use remote sensing data to assess sediment runoff, air pollution, and the impact of pollution on natural resources.

Within the Department of Agriculture, FAS has been the primary user and beneficiary of the results of the AgRISTARS research. Outside the USDA, NOAA has refined and made extensive use of the techniques for combining surface data with weather satellite imagery to assess crop conditions. AID also benefitted from the USDA-NOAA research.

NASS is adding crop estimates using LANDSAT data for two new States each year. Within the past year, however, because of decreases in funding, NASS has cut back on its remote sensing research. NASS is now concentrating on getting ready for the launch of LANDSAT 6 and will take advantage of the anticipated improvements in the resolution of satellite imagery.

NASS has also conducted research on improved methods for forecasting and estimating crop yields for both domestic and foreign application. The research involves the development of models which utilize relationships between crop yields and such environmental factors as weather, soils, incidence of disease, pests, and cropping practices. The models incorporate both surface and satellite data. Of particular interest are the weather-crop models for the main grain producing regions for the USSR which are used in making forecasts and estimates of the annual Soviet grain crop.

Providing technical assistance to developing countries on techniques for gathering and analyzing agricultural data under the auspices of AID is another NASS function. Some of this technical assistance involves the use of remote sensing data in combination with ground and statistical data to make forecasts or to plan agricultural development projects.

WORLD AGRICULTURAL OUTLOOK BOARD

The World Board, a USDA agency that reports to the Assistant Secretary of Agriculture for Economics, has responsibility for review and clearance of all commodity and aggregate agricultural and food related estimates reported by the USDA. The World Board has the responsibility for chairing all the inter-agency (within USDA) commodity estimates committees on which sit representatives of FAS, ERS, NASS, and the Agricultural Stabilization and Conservation Service (ASCS), the agency responsible for administering domestic price support programs. The World Board holds regular "lock-ups," that is, closed-door sessions, during which differences between agencies and analysts involved in making country and commodity agricultural and food assessments are worked out prior to making official reports. Agencies outside USDA with particular interest in the estimates under review participate in World Board procedures. For example, NOAA staff in the Joint Agricultural Weather Facility participate regularly in World Board "lock-ups;" the Central Intelligence Agency (CIA) may

be represented when Soviet grain estimates are under consideration. AID participates in the World Board's review and clearance of the legislatively mandated global assessment of food needs and availabilities.

Within the USDA, the World Board has been assigned the responsibility of coordinating weather, climate and remote sensing research, and forecasting and conducting cooperative activities in these areas with agencies outside the USDA. In this respect, the World Board and NOAA operate the Joint Agricultural Weather Facility housed in the USDA complex in Washington. Using remote sensing data from polar orbiting satellites, the JWF provides a daily review of significant weather developments around the world and their implications for agricultural and food production. The JWF publishes a weekly weather and crop bulletin highlighting developments around the world and conducts special briefings on the effects on agriculture of actual or potential weather developments.

RESOURCE MANAGEMENT AGENCIES IN USDA

USDA rarely looks at remote sensing data alone in carrying out its resource management functions, but combines it with other data bases, including ground observation and statistical information. Remote sensing data are combined in digital form with weather data, terrain data, and transportation networks to create a Geographic Information System (GIS). Researchers use computers to collect and analyze large amounts of data in a GIS as a tool to understand, plan, and manage problems or tasks.[14]

USDA has established a Remote Sensing Laboratory as part of the Agricultural Research Service (ARS) which is working to improve USDA's ability to use satellite data for resource management purposes.[15]

For resource management, USDA uses primarily LANDSAT rather than AVHRR data because LANDSAT offers much higher resolution. USDA has also used some SPOT data on a developmental basis. The Soil Conservation Service (SCS) and the Forest Service (FS) use the data to monitor soil, water or natural resource conditions and to conduct resource inventories. ARS and SCS have analyzed LANDSAT images for saline and alkaline soil problems. The Forest Service has done inventories of specific kinds of trees, such as logpole pines, which had been subject to insect or acid rain damage. The Forest Service has inventoried habitats where wildlife, such as the grizzly bear and spotted owl, have been endangered. Finally, the Forest Service participates in a program to track and warn areas that are potentially vulnerable to wildfire. ASCS used remote sensing data in order to identify and monitor agricultural areas which were stricken by last summer's drought.

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[14] According to Richard McArdle, Remote Sensing Coordinator, in the World Agricultural Outlook Board, USDA still uses a tremendous amount of data gathered from aircraft because it is worried about the future of LANDSAT and the possible lack of continuous data. Telephone conversation, July 10, 1989.

[15] NASA. Aeronautics and Space Report of the President. 1986 Activities, p. 97.

U.S. Agency For International Development

The Agency for International Development (AID) is the U.S. Government agency with primary responsibility for administering programs of foreign assistance in developing countries, including disaster relief and foreign food donation programs. AID shares responsibility for administering these foreign food aid programs with USDA. As in the case of USDA, AID uses remote sensing data combined with ground and statistical data both for agricultural and environmental assessment and for resource management. AID's focus is exclusively on low-income developing countries that are recipients of U.S. foreign assistance.

The Office of Foreign Disaster Assistance, the Bureau of Food for Peace, and the Africa Bureau are the main organizational units within AID currently involved in determining where food assistance is needed, what type of commodities would be appropriate, when timing of harvests or planting would prohibit food aid deliveries, and the logistics of distributing the food; that is, port facilities, storage facilities, road or rail systems.

To administer the food aid program, AID requires timely and reliable information on what the needs are, as well as on the crop conditions and weather for future plantings and harvests. This information comes from NOAA's polar orbiting satellites; from USDA's congressionally mandated assessment of global food production and needs; and from reporting cables from the AID missions located in nearly every drought-affected or chronically food-short country in the developing world.

These information flows are coordinated by the Interagency Food Aid Analysis Working Group which was created in 1984 by President Reagan. The Working Group is chaired by the USDA's Economic Research Service. The purpose of the interagency group is to foster cooperation among the agencies which work on foreign food aid issues, to obtain earlier warnings of drought and famine and to improve the food aid decision-making process. This Working Group has responsibility for the report, *World Food Needs and Availabilities* (prepared in ERS), which contains estimates of food aid needs of low-income developing countries. The report, formerly an annual report, now includes biennial updates to improve the accuracy and timeliness of estimates of food needs in food-short countries.

AID obtains most of its information on food supply and demand conditions in the developing countries, including information on drought and famines from external sources; for example, USDA, NOAA, NASA, or contractors (private firms and universities). In 1977, AID's Office of Foreign Disaster Assistance began cooperating with NOAA and NASA in implementing a regional early warning system—the Operational Drought/Disaster Early Warning Program. The Department of Defense (DOD) and the U.S. Geological Survey (USGS) also cooperated in this project. The purpose of the project was to predict crop failure, drought, and flooding. Although it monitored all types of disasters, this program included the early warning of food shortages by providing a biweekly drought/crop condition assessment originating from NOAA weather satellite monitoring. This assessment contained information on crop, weather and rangeland conditions in the Sahel and Horn of Africa.

From 1977 to 1985, NOAA used remote sensing data, primarily from the AVHRR sensor on NOAA satellites and from Europe's METEOSAT (see below), to provide early warning of drought and other disasters. NOAA also used some ground data to recognize the onset of drought conditions. NOAA found that it could reliably assess a drought 30 to 60 days before crop harvesting, thus providing a 90- to 180-day lead time to deal with food shortages.[16]

During the 1984–85 drought in Africa, AID began to generate its own information on food supply and demand in countries that are most severely affected by drought. AID instituted field reporting on the food situation, growing conditions, and weather in Africa. Africa Bureau personnel in Washington received this information from the missions, calculated local food availability and consumption needs, and determined the countries' commodity needs for supplemental food aid in the 1984–85 fiscal year. These estimates were used as a partial basis for the administration's request for supplemental food aid appropriations for Africa for fiscal year 1985. In the intervening years, AID has continued to rely on field reporting as a major source of information to be combined with data from other sources including satellites in making its food needs assessments.

In mid-1985, AID announced the establishment of a Famine Early Warning System (FEWS) for the forecasting of inadequate harvests and pending food shortages. This system built on the AID-supported NOAA project for doing agroclimatic assessments and early warning of drought and food shortages. NOAA and AID produced monthly reports for internal and interagency distribution containing analysis and forecasting of African rainfall, climate and crop conditions, as well as rangeland conditions. Currently, AID contracts with a private firm and university to implement its Famine Early Warning System (FEWS). FEWS uses weather information from NOAA and vegetation indices from NASA in making assessments of crop and environmental conditions in sub-Saharan Africa.

AID, in cooperation with the French Government, also carries out the agriculture-hydrology-meteorology project (AGRHYMET), a Sahel region project, based in Niger.[17] AGRHYMET will become the source for remotely sensed data from NOAA satellites for nine West African countries. A receiving station for NOAA AVHRR data was installed at the AGRHYMET Regional Center in Niamey, Niger, last September. Vegetation index data, calculated from AVHRR, has been provided to selected countries during the 1989 agricultural season. AGRHYMET plans to be fully operational by 1990 and will provide vegetation index data to all nine countries. The member countries provide surveillance of the status of agricultural development during the growing season. They prepare assessments every 10 days of the current situation. These reports are sent to ministries, donors, and other organizations involved in food security and agriculture. The vegetation index data will be used to

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[16] U.S. House of Representatives. 99th Congress. 1st sess. Committee on Science and Technology. Hearings. Africa and Hunger: Prospects for Sustainable Development in Sub-Saharan Africa. September 19, 1985, pp. 36, 51.

[17] EROS Data Center. National Mapping Division. U.S. Geological Survey. Requirements Needs Analysis: AGRHYMET Phase III, June, 1988.

Lessons Learned From Remote Sensing in the Sahel

In 1988, the Club du Sahel, a multidonor organization, that fosters cooperation between developed countries that are members of the Organization for Economic Cooperation and Development (OECD) and eight drought-prone West African countries—Burkina Faso, Cape Verde, Chad, Gambia, Mali, Mauritania, Niger, and Senegal—commissioned a study of satellite remote sensing (RS) of the Sahel. The report inventoried and assessed almost 50 remote sensing projects and drew lessons for the application of satellite technology to the Sahel countries:

- Certain limitations are emerging: atmospheric phenomena lend themselves better to RS than do ground-level features; RS seems to be very useful in climatology, indispensable in pluviometry, less useful in crop monitoring, although here vegetation indices are of some utility. Its utility in yield forecasting seems still more uncertain, and crop forecasting runs into major technical and economic difficulties in attempts to measure cropland acreage and discriminate between crop types;
- Use of RS data should improve in the near future: RS techniques in general are expanding fast, and progress is expected in the Sahel on the operational environment side (high resolution picture transmission receiving stations for NOAA data at the regional AGRHYMET center, telecommunications, microcomputers, et cetera) and on the operations management side (training of specialists, on the job or through outside courses);
- The spin-off from RS will primarily benefit national and regional early warning systems, decision-makers in cropping and livestock sectors and, to a lesser extent, the agricultural statistics services. Nor should more specific applications be overlooked: floodland cropping, environment, locust control, and forest clearance are all fields in which satellite techniques are often the only ones practicable on the scale required for the Sahel's vast open spaces;
- It is not wise to try to use either RS or ground-based methods exclusively. More often than not the two techniques must be combined. The optimum role of each has yet to be established, however, and this demands experimentation and real cooperation between all those involved.

From OECD. Club du Sahel. Satellite Remote Sensing of the Sahel. OECD. Paris. 1988.

determine the status of crop development, evaluate rainfall patterns, and identify potential pest problems. AGRHYMET will basically become the operational arm for remotely sensed data needed for food security monitoring in West Africa.

Under this project, AID provides image processing equipment and training in the use of remote sensing data. NOAA also participates in the project, particularly in training on the use of AVHRR data to estimate crop yields. AID has also contracted with the U.S. Geological Survey to help African countries monitor and control the spread of Desert Locusts in Africa. (See box.)

Remote Sensing and Locust Control in Africa

With the return to near normal rainfall during recent years, conditions favorable for locusts and grasshoppers have resulted in large populations of these insects. In 1985 and 1986, the Senegalese Grasshopper threatened cropland in a number of West African countries. In mid-1987, the Desert Locust threatened crops in vast areas of North Africa.

In early 1987, AID prepared for a major campaign to control these pests. One goal was to improve grasshopper-locust prediction and survey techniques. The Africa Bureau of AID requested the EROS data center of USGS to conduct a pilot project to develop, test, and evaluate a near-real-time monitoring procedure using satellite data.

Inherent in the pilot project was the need to present information for use by decision-makers and grasshopper control technicians. The information was presented in the form of vegetation indexes or "greenness" maps derived from 2-week composites of local area coverage satellite data from the AVHRR. These maps use a vegetation index which is useful for monitoring seasonal fluctuations in vegetation. Grasshopper and locust control teams used the maps for planning and conducting field and aerial surveys and for locating infestation areas more efficiently. This program operated in support of efforts to control grasshoppers and locusts in Mauritania, Mali, Niger, Chad, Sudan, Morocco, Algeria, and Tunisia.

From: U.S. Geological Survey. Seasonal Vegetation Monitoring With AVHRR Data for Grasshopper and Locust Control in West Africa. Presented at the 22nd International Symposium on Remote Sensing of Environment, Abidjan, Cote d'Ivoire, October 20–26, 1988.

AID also sponsors large surveying and mapping projects in Egypt, primarily for the purpose of irrigation and agricultural management. In India, Haiti and Ecuador, AID is conducting survey projects in order to advise U.S. missions. Climate monitoring is the focus of a project in Bangladesh, in which AID provides a satellite receiving station for the NOAA polar orbiting weather satellite and Japan's geostationary weather satellite (see below). The project's aim is to monitor monsoons and other weather patterns, and eventually improve Bangladesh's capacity to manage agriculture and forestry resources.

INTERNATIONAL ORGANIZATIONS INVOLVED IN AGRICULTURAL AND ENVIRONMENTAL ASSESSMENTS

Three international organizations have programs for monitoring agricultural and environmental conditions. These organizations are the United Nations Food and Agriculture Organization (FAO), the World Meteorological Organization (WMO), and the United Nations Environment Program (UNEP).

U.N. Food and Agricultural Organization

FAO's original function was to collect and disseminate agricultural information. The organization now also carries out programs of development assistance in the developing countries. Information gathering and dissemination remain, however, a primary responsibility of FAO.

The Global Information and Early Warning System on Food and Agriculture (GIEWS), established on the recommendations of the 1973 FAO Conference and the 1974 World Food Conference in Rome, is the main organizational unit within FAO that monitors and forecasts drought and famine.[18] The system has been in operation since 1975 and has two main objectives as stated in the World Food Conference resolution calling for the establishment of the GIEWS: (1) to monitor continuously the world supply/demand outlook for basic foods and fertilizers; and (2) to identify individual countries and regions where serious food shortages are imminent, and assess possible emergency food requirements.

While all members of FAO are eligible to participate in the early warning system, currently about 98 countries, the European Community, and the Permanent Secretariat of the General Treaty on Central American Economic Integration (SIECA) actually do take part. Participation creates a two-way street: the participating country provides to the system on a voluntary basis raw data and ground information, while receiving the analysis and forecasting which is performed by FAO analysts within the Early Warning System.

The system's monitoring is designed to cover the global supply and demand for all major food and feed commodities, but major emphasis is given to cereal crops. Within individual countries, the system pays particular attention to the local staples including pulses, roots and tubers, as well as any livestock that may be significant to the local diet.

Satellite monitoring of food crop conditions is accomplished largely through the utilization of the European weather satellite (METEOSAT) and NOAA weather satellites. Analysis of the satel-

[18] FAO, The Global Information and Early Warning System on Food and Agriculture, Rome, 1983.

lite imagery is combined with ground monitoring, as well as expertise and information from other international agencies such as the United Nations Disaster Relief Organization, World Health Organization, World Meteorological Organization (WMO), and the International Wheat Council.

FAO maintains field staff in the vast majority of critical or potentially critical food-deficit countries throughout the world; and wherever there is no FAO staff, quite often ground information is provided to FAO via the World Food Program advisors located in those areas. The FAO and WFP field staffs report regularly on the local food and crop situation as well as consumption needs. In many of these countries basic food supply/demand information is not compiled on a regular and systematic basis by the local governments. Therefore, it has often been the case in the past that FAO or WFP field staffs were the only ones collecting and disseminating such information on a historical and continual basis. The FAO field staff send out regular reports to the central unit within FAO; however, during a crisis or in the event of a severe food shortage, the FAO representative telexes reports and frequent updates of the food supply/demand situation in that country or region, emphasizing early signs of crop failures, rainfall changes, lower than expected market produce, and signs of rising wholesale prices. Furthermore, the FAO field staff assist local governments in collecting and assessing food import needs.

The GIEWS seeks to establish a local monitoring system within each participating country. Particular attention is currently being given to establishing and improving national early warning systems since the countries most likely to be affected by food shortages are usually the countries least equipped with an adequate system for monitoring and assessing food supply and demand conditions.

The large volume and varying types of information accumulated within the Early Warning System are coordinated through the central unit, a small group of analysts who work within FAO's Commodity and Trade Division of the Economic and Social Policy Department. This unit is responsible for organizing and analyzing the information that is provided by FAO and WFP field staff and then coordinating it with the satellite data and information received from other FAO divisions and other international agencies. In addition, the central unit distributes information to countries that are members of the GIEWS.

The United States participates in FAO's Early Warning System as a member country of the United Nations and as a major contributor to the World Food Program which provides some of the funding for this program. In addition, the U.S. Department of Agriculture exchanges information with FAO on an informal basis, providing weather station data which supplements FAO's data.

Dissemination of information through the Early Warning System is accomplished through a number of reports. The *Food Outlook* report provides a monthly analysis of the global food situation, including prospects for production, stocks, exports, imports, food aid, and prices. This report covers cereals, sugar, oilseeds, oils, and fats, cassava, pulses, milk and milk products, meat, and fertilizers. The *Food Outlook Statistical Supplement* covers similar aspects of

global food issues, but with a longer time horizon; it provides historical data and is updated annually. *Foodcrops and Shortages* is a monthly report which provides information on a country-by-country basis of the food supply and demand situation. This report identifies countries where crop conditions give cause for concern or where the conditions are critical. FAO issues *Special Alerts* whenever the food situation becomes especially threatening in a country or region. Alerts are telexed to potential food aid donors so that quick action can be taken. Wherever sustained food shortages occur, FAO issues *Special Reports* as has been the case with the continuing African famine when donor countries requested regular reports on the food supply and import capabilities of the 26 most critically affected nations.

FAO also provides technical assistance to developing countries on techniques for gathering and analyzing agricultural data. Most of the technical assistance concerning the use of satellite technology is carried out by FAO's Remote Sensing Centre established in 1980.[19] This Centre advises developing countries on the use of remote sensing data, provides training in remote sensing applications, and conducts research and development in the use of remote sensing data. According to the FAO, it has used remote sensing data in projects in over 70 developing countries for purposes including: land use, forest and soil surveys, monitoring changes in land use and desertification, assessment of food and insect damage.[20] The Remote Sensing Centre is working with NASA, the Universities of Reading and Bristol in the United Kingdom to improve GIEWS monitoring capability.[21]

In 1988, FAO implemented a new program called ARTEMIS, Africa Real Time Environmental Monitoring using Imaging Satellites. ARTEMIS also uses data from the METEOSAT and NOAA weather satellites. The Netherlands National Aerospace Laboratory (primary contractor), NASA, and the Universities of Reading and Bristol designed the system for FAO. ARTEMIS supplies data for GIEWS. A new communications system, called DIANA, uses Intelsat communications satellites to disseminate the information, currently on a demonstration basis, to five terminals in Africa.[22] The goals of the ARTEMIS program are to (1) identify in advance agricultural areas threatened by drought; (2) identify areas which might breed desert locusts, and (3) allow faster and more accurate mapping and monitoring of tropical forests.[23]

World Meteorological Organization

The World Meteorological Organization is the international organization responsible for weather and climate monitoring. WMO serves as coordinator for the exchange of weather satellite data and ground observations worldwide. Among the many activities of

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[19] FAO. Remote Sensing Centre. November 1987, p. 1.

[20] Ibid.

[21] Hielkema, Jelle U. Operational Satellite Environmental Monitoring for Food Security by FAO: The ARTEMIS SYSTEM, p. 2.

[22] Ibid.

[23] Highlights of FAO Remote Sensing Activities in 1988. Statement of FAO Representative Z.D. Kalensky, at the 26th session of the Scientific and Technical sub-committee of UN COPUOS, p. 4.

WMO, three are of particular interest to the agencies monitoring world food/crop situations—WMO's World Weather Watch Program (WWW), their World Climate Program (WCP), and the Research and Development Program (RDP).

The World Weather Watch, established in 1967, has a primary purpose of providing each national meteorological service with weather, climate, and other available environmental information. Three units within the WWW are responsible for providing different aspects of weather information. The Global Observing System (GOS) provides information obtained through various forms of observations—ground weather stations, radar, aerial photography, and satellite imagery. The Global Data-Processing System (GDPS) provides computer-processed information. The Global Telecommunications System (GTS) links all GDPS centers, providing rapid and accurate transfer of information throughout the world. The GTS exchanges raw data, observations, forecasts, analyses, and warnings. Both AID and USDA are recipients of the GTS information through NOAA.

The World Climate Program, established in 1979, does research and education on climatic variability and change. Numerous international agencies are involved in this program, including FAO and the United Nations Environmental Program (UNEP) (see below). WCP performs research on a longer term than WWW, observing long-term trends in climate changes. This information is available worldwide, complementing the food/crop monitoring agencies' shorter term weather information.[24]

WMO is also involved in the International Satellite and Land Surface Climatology Program (ISLSCP). In association with the International Council of Scientific Unions (ICSU), ISLSCP is planning to use data from NOAA, ESA, Japanese and Indian weather satellites to produce validated data sets on land surface reflectance (albedo), land surface temperature, vegetation cover, evaporation, and transpiration.[25]

In 1987–88, 150 scientists from over 30 institutions participated in the First ISLSCP Field Experiment (FIFE). NASA managed the experiment, which included other U.S. agencies, plus the Canadian Centre for Remote Sensing and the United Kingdom's National Environmental Research Centre. FIFE was the most comprehensive set of satellite data ever compiled for a single site, the Konza Prairie in Kansas. Data sources included aircraft sensors, NOAA's AVHRR, LANDSAT's TM and France's SPOT. NASA's goal was "to develop and validate algorithms to retrieve land surface properties and the fluxes of moisture between the land surface and the atmosphere at the 15 km scale".[26]

WMO's Research and Development Program includes research on weather, climate, and other environmental factors in relation to agricultural production and development. The program also facilitates the exchange and coordination of projects or findings. AID, USDA, NOAA, and FAO receive WMO information and use it in

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[24] Worldmark Encyclopedia of the Nations, Worldmark Press, Ltd., John Wiley, Inc. 1983.

[25] Testimony of Dr. Robert T. Watson, NASA, ESAD, before the Senate Commerce Committee, July 13, 1988, p. 4.

[26] NASA. ESAD. September 1988, p. 34.

their respective monitoring and early warning programs. WMO has also conducted training programs on agricultural meteorology in developing countries, including Dominica, Rwanda, and Uruguay.[27]

United Nations Environment Program

The United Nations Environment Programme (UNEP) operates the Global Environmental Monitoring System (GEMS) as part of its Earthwatch Program. The GEMS system includes monitoring a number of environmental factors around the world, using a variety of information collection techniques. Among these is the use of satellite remote sensing, along with other techniques such as questionnaires, sampling of soil, glaciers, and other methods of collecting environmental data. It also assists countries in assessing their monitoring needs and planning monitoring programs, which may involve plans for use of satellite data by these countries.

UNEP does not operate satellites or, in most cases, carry out the data analysis. It may contribute funding along with other U.N. agencies to joint efforts that utilize satellite data from LANDSAT or other nations' satellite systems. In its renewable resource monitoring activities, in conjunction with FAO, EC, NASA, and other national and international agencies, UNEP is contributing to development of a satellite-based methodology to map and monitor tropical forests. NASA's tropical forest monitoring research activitieswill contribute to development of methods to monitor forest and vegetation cover; if the methodology proves to be successful, the joint effort will be expanded to provide monitoring of wider regions and finally to global coverage.[28]

UNEP is supporting global climate system monitoring carried out by the World Meteorological Organization (WMO).

The environmental data management system of GEMS is called the Global Resource Information Data base (GRID). This is a system designed to collect data bases from all sources around the world on natural resources and the environment, in order to make them available to nations for environmental decision-making. According to UNEP, GRID "was established on the premise that basic environmental data—on soils, forests, hydrology, vegetation, land use, climate and pollution—need to be more readily available, especially in developing countries, to both national and international environmental decision-makers and managers." [29]

NASA has contributed data bases to GRID, along with other countries. But until recently, UNEP did not have the computer capacity required to accept and manage a truly comprehensive data collection. A recent contribution of computer equipment has provided additional capacity to GRID, but it remains for the necessary data bases to be developed and contributed to it to make the system global and comprehensive in its coverage.

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[27] WMO. Annual Report of the WMO. 1986, pp. 20–27, 76–77.

[28] United Nations Environment Programme. *1988 Annual Report of the Executive Director.* UNEP/GC.15/4. Nairobi, Kenya, 1989, p. 20.

[29] Ibid., p. 22.

SATELLITE TECHNOLOGY: CURRENT SITUATION AND FUTURE DEVELOPMENTS

U.S. Weather Satellites

The United States operates two separate weather satellite systems. NOAA operates the civilian weather satellite system which usually is comprised of two polar orbiting environmental satellites (referred to either as POES or simply NOAA) and two geostationary weather satellites (GOES). The Department of Defense operates polar orbiting weather satellites, called DMSP. For the purposes of environmental and crop monitoring, the most important weather satellite sensor is the AVHRR, carried on the polar orbiting NOAA satellites. Under a 1983 Basic Agreement between NASA and NOAA, NOAA establishes the operational requirements for both polar and geostationary requirements. NASA procures spacecraft and instruments required to meet those standards. NASA obtains launches for the satellites from the private sector and does initial in-orbit checks of the spacecraft. Then NOAA assumes operational responsibility.

POLAR ORBITING WEATHER SATELLITES (NOAA)

Usually two NOAA satellites are in orbit at any one time, crossing the equator at 7 a.m. and 2 p.m. A polar orbiting satellite orbits the Earth around the North and South Poles, and, as the Earth rotates, the satellite can view and return data about the entire planet, returning to cover the same target at the same time (either 7 a.m. or 2 p.m.) each day.

The current NOAA satellites are the fourth generation of TIROS (television infrared observation satellites). The United States launched ten experimental satellites, called TIROS, during 1960–65, followed by nine operational satellites, called ESSA, from 1966–69. The next series, ITOS, consisted of five satellites launched from 1970–76. Following successful launch, each of these was designated NOAA–1 through 5. The prototype of the next generation of polar orbiting weather satellites, TIROS–N, was launched in 1977.[30] The operational satellites, designated NOAA–6 and up, have been launched since then. Currently, NOAA–10 and 11 are the primary operational polar orbiting weather satellites. NOAA–9 continues to return data on the ozone and the Earth radiation budget. NOAA–11 is carrying several improved sensors. The satellites are generally launched at 2 year intervals. NOAA–D and NOAA–I are scheduled for launch in January 1990 and May 1991, respectively. These

[30] This was the last experimental satellite in this series that was developed by NASA. For more information see: U.S. Congress. House. Committee on Science and Technology. United States Civilian Space Programs. Volume II: Applications Satellites. 98th cong., 1st sess. Prepared by the Congressional Research Service. Washington, U.S. Govt. Print. Off., 1983. pp. 199–206.

satellites will become NOAA-12 and NOAA-13 after they are successfully launched.

NOAA satellites carry seven different instruments to measure various aspects of the weather and the Earth's surface, including sea surface temperature, snow cover, and vegetation. Each satellite also carries a data collection system. The principal products derived from polar orbiting satellites are: (1) vertical temperature and moisture soundings, (2) sea surface temperature measurements, (3) global cloud cover images and mosaics, (4) crop assessments for agricultural monitoring, and (5) total ozone measurements.[31]

The primary payload on the NOAA satellites is the TIROS Operational Vertical Sounder (TOVS). TOVS itself is comprised of three instruments: a high resolution infrared sounder (HIRS/2), a microwave sounding unit (MSU), and a stratospheric sounding unit (SSU). The HIRS on board current NOAA satellites is a second generation instrument (and therefore called HIRS/2) and records temperature and moisture profiles. HIRS/2 has 20 channels to measure the temperature over the Earth's surface, the water vapor content of three layers in the atmosphere, and the total ozone content of the atmosphere. The SSU, which is built and funded by the United Kingdom, provides atmospheric sounding and temperature profiles.

The next major instrument on NOAA is the advanced very high resolution radiometer (AVHRR), which has proven very useful for environmental and crop monitoring. The AVHRR is a second generation sensor and gathers data in five channels—one in the visible, one in the near-infrared, and three in the thermal-infrared regions. The AVHRR measures cloud temperature, sea surface temperature, and land temperature, and is indispensable in producing a vegetation index of the Earth. AVHRR produces imagery and digital data at both 1 and 4 kilometers resolution, approximately one-tenth the spatial resolution of LANDSAT's MSS (see below).

NOAA polar orbiting weather satellites also carry a space environment monitor (SEM) which measures solar protons, alpha particles, and "e" flux density. Since 1984, NOAA satellites have also carried a solar backscatter ultraviolet experiment (SBUV/2), now also in its second generation, to measure the solar spectrum, provide ozone profiles, and Earth radiance spectrum; and an Earth radiation budget experiment (ERBE) which measures the Earth's radiation loss and gain.

All NOAA satellites carry the Argos Data Collection System (DCS). France supplies the DCS which collects data from buoys, balloons and platforms all over the Earth's surface and atmosphere.

NASA, acting for NOAA, ordered three additional satellites, NOAA-K, L, and M, in July 1988. They will essentially be the same as previous NOAA satellites, but with an improved sounding unit, called the advanced microwave sounding unit, AMSU. The AMSU will replace two instruments in the TOVS (the SSU and the MSU), and will have greatly improved microwave capability. The

[31] Today, NOAA satellites are also equipped with search and rescue instruments that can detect emergency locator transmitters on ships and aircraft in distress.

improved capability will result in more accurate precipitation estimates.

GEOSTATIONARY WEATHER SATELLITES (GOES)

There are usually two GOES satellites in orbit, designated GOES-E, in the east, and GOES-W, in the west. Following the January 1989 failure of GOES-W, however, only the GOES-E satellite is operating. The next GOES launch is scheduled for July 1990. Until then, GOES-E will be placed in an easterly position for the summer hurricane season and a westerly position for the winter storm season.

NASA began research on geostationary weather satellites with the launch of the first Applications Technology Satellite (ATS) in 1966. This was followed in 1974 by the first NASA Synchronous Meteorological Satellite (SMS). NASA launched SMS-2 in early 1975. Later that year, NASA launched the first Geostationary Operational Environmental Satellite, GOES-1. GOES-2 joined it in orbit in 1977 and GOES-3 replaced GOES-1 in 1978. The principal instrument on the SMS and first three GOES satellites was the Visible and Infrared Spin Scan Radiometer (VISSR) which takes visual images of the Earth's surface and cloud cover and infrared sea surface temperature data. Beginning with GOES-4, launched in 1980, an improved version of VISSR, called the VISSR Atmospheric Sounder (VAS), was used. The GOES-E that will be launched in 1990 will carry an improved GOES imager which will have an increased number of infrared bands and increased infrared resolution, which will, for example, improve NOAA's ability to warn the citrus industry of frost.

Data from VAS are used in forecasting and monitoring storm strength and severe storms. GOES also carries a Data Collection System (DCS). Although GOES is vitally important for weather forecasting and storm warning services, it is not as useful as NOAA data for crop forecasting or environmental monitoring. It can, however, add data to general weather forecasting and trend monitoring.

APPLICATIONS OF CIVILIAN WEATHER SATELLITE DATA

Data from NOAA and GOES are used to monitor vegetation directly, monitor weather conditions that will affect crop growth, and monitor specific events, such as the burning of tropical rain forests. The AVHRR on the NOAA polar orbiting satellites gathers data which is processed into a vegetation index that can measure the amount and health of the vegetation. The health and density of the vegetation, combined with precipitation data, are directly related to the crop yield. NOAA, USDA, and other organizations have studied the relationship between the vegetation index, precipitation data, and crop yield extensively in order to improve crop yield estimates. The GOES satellites gather data used to estimate the amount of precipitation by measuring the type and altitude of clouds. GOES data can also help estimate temperatures below freezing that might damage crops.

DEPARTMENT OF DEFENSE WEATHER SATELLITES

The Air Force operates the Defense Meteorological Satellite Program (DMSP) for the Defense Department's use in military activities. The Defense Department has made data from DMSP satellites available to NOAA, and vice versa. DMSP is a polar orbiting satellite similar to the NOAA series, although it carries some more specialized instruments. Current DMSP satellites carry a microwave radiometer. NASA hopes to acquire data on sea ice, snow cover, and atmospheric water for research purposes from this sensor.[32]

LAND REMOTE SENSING: LANDSAT

NASA developed and launched the first land remote sensing satellite in 1972. The satellite was originally named Earth Resources Technology Satellite (ERTS–1), but was later renamed LANDSAT. LANDSAT 2 was launched in 1975, and LANDSAT 3 in 1978. Currently, LANDSAT 4, launched in 1982, and LANDSAT 5, launched in 1984, are in orbit and continue to return land remote sensing data.

LANDSAT satellites orbit the Earth in a polar orbit, returning to cover the same path over the Earth every 16 days. LANDSAT's 4 and 5 carry two sensors: the multi-spectral scanner (MSS) and the thematic mapper (TM). MSS has been on every LANDSAT, while TM was first added as a new instrument on LANDSAT 4. MSS receives data in four spectral bands and has a resolution of 80 meters. TM has 6 bands that measure visible or near infrared light with a 30 meter resolution.[33] It also has one thermal band that measures infrared light with a resolution of 120 meters. LANDSAT 6 will carry an Enhanced Thematic Mapper which includes a 15 meter capability in the black and white band. This capability will improve accuracy when mapping small agricultural features.

There are 16 international ground data receiving centers in: Canada, Brazil, Argentina, Sweden, Italy, Spain, South Africa, Saudi Arabia, Pakistan, India, Indonesia, Australia, Japan, Thailand, China, and Japan. These centers pay an annual fee which allows them access to all LANDSAT data for their own use and to sell to other users. For many years, these ground stations also played an important role as receiving stations to allow LANDSAT coverage of more of the world. LANDSAT's 1, 2, and 3 carried recorders with a 30-minute recording capability, allowing coverage outside the range of a ground station. LANDSAT's 4 and 5 do not carry recorders, so data must be transmitted immediately, in "real time". NASA has launched three TDRSS (Tracking and Data Relay Satellite System) satellites which provide an orbiting data link, and data can either be transmitted through TDRSS directly to the U.S. TDRSS receiving station, or to the individual ground stations.

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[32] NASA. Earth Science and Applications Division (ESAD). The Program and Plans for FY 1987–1988–1989. May 1987, p. 47.

[33] Resolution is the sensor's ability to see or register different objects on the ground. Specifically, a sensor with a resolution of 30 meters would be able to distinguish two different features that are 30 meters apart.

LANDSAT'S TRAUMATIC HISTORY

NASA developed and operated the LANDSAT system during the development phase. The Carter administration decided in 1979 that LANDSAT could be considered fully operational and therefore should be shifted to the Department of Commerce, but in two steps. In 1979, the Commerce Department's National Oceanic and Atmospheric Administration (NOAA) assumed responsibility for the operations of the MSS sensor, which has flown on all the LANDSAT satellites. Responsibility for the Thematic Mapper was transferred to NOAA later, since it was first used on LANDSAT 4, launched in 1982. The Carter administration planned for LANDSAT operations to be eventually taken over by the private sector, after approximately 10 years of operation by NOAA.

The Reagan administration accelerated these plans to transfer LANDSAT to the private sector and, in 1984, Congress passed the Land Remote Sensing Commercialization Act (Public Law 98-365) which initiated a process for private companies to bid on the commercial operation of the existing LANDSAT satellites and develop follow-on satellites. Through a competitive bidding process, NOAA selected a private company, EOSAT, to operate the existing LANDSAT's (LANDSAT 4 and 5) under contract to the Government, and build two follow-on satellites (LANDSAT 6 and 7) on a commercial basis, but with a Government subsidy of $250 million over 5 years. The Government also agreed to pay for launching the two new satellites.

The Government's funding for EOSAT has been disputed or delayed in fiscal years 1986, 1987, and 1988.[34] While this affected primarily development of the new LANDSAT 6 and 7 satellites, in the spring of 1989, NOAA announced that it would cease operating the existing LANDSAT 4 and 5 satellites on April 1 due to lack of funding.[35] Intervention by the newly formed National Space Council allowed continued operations of LANDSAT 4 and 5, and eventually won President Bush's approval for future Government support for the existing satellites and LANDSAT 6. The administration has not made clear, however, where the funds for LANDSAT operations are coming from, nor where they will come from in the future. While the administration has expressed support for one follow-on satellite (LANDSAT 6), the status of LANDSAT 7 is more uncertain.

COST

When the Government operated LANDSAT in the 1970's, sales of LANDSAT data did not cover the cost of building and operating the satellite system. During the 1980's, as a result of the decision to make LANDSAT an operational system, the Government gradually increased data prices. In the late 1970's, photographic image products cost between $10 and $100, MS computer compatible tapes (CCTs) cost $200. In 1983, photographic images cost between $35

[34] For a detailed account, see: The Future of the Land Remote Sensing Satellite System (Landsat), CRS Rept. 89-242 SPR, by Karl A. Rohrer and Marcia S. Smith, April 13, 1989.

[35] The Reagan administration had not requested any funding for LANDSAT operations in the fiscal year 1989 budget. Congress added funds sufficient for 6 months of operation (through March 1989).

and $370, MS CCTs cost $650 and newly available TM CCTs cost $2,800. By 1985, before EOSAT took over operations, photographic images cost $40 to $415, MS CCTs cost $730, and TM CCTs cost $4,440. After EOSAT began operations, photographic images again rose in price to $50–$650, but CCTs decreased to $660 for MS CCTs and $3,300 for TM CCTs.[36] In addition, in 1983, foreign ground station annual fees rose from $200,000 to $600,000.[37] Data sales still lag far behind operations costs, however, and several recent studies have stated that LANDSAT will not be a commercially viable system until after the year 2000 because of the limited market, the costs of technology, and foreign competition.[38]

DATA CONTINUITY

LANDSAT 4 and 5 were each designed with a 3-year life expectancy. Due to an early partial failure of LANDSAT 4 (after 2 years of operations), LANDSAT 5 was launched somewhat sooner than originally planned, in 1984. Thus, LANDSAT 4 and 5 each are past their design lives and could fail at any time. LANDSAT 6 is under construction, but will not be ready for launch until July 1991. (EOSAT delayed work on LANDSAT 6 for 18 months because of lack of funding.) Thus, there is a strong possibility that there will be a gap, that is, a period of months or years when there is no operating LANDSAT satellite.

Also, as a result of funding difficulties, EOSAT renegotiated its contract with NOAA and no longer plans to build a LANDSAT 7. Currently, there are no plans for the private sector or the Federal Government to build or operate LANDSAT satellites after LANDSAT 6. Although the National Space Council has endorsed continued Government support of the LANDSAT program, it has not yet been decided if and when LANDSAT 7 will be built.

Scientists who use LANDSAT data stress the importance of data continuity. They need data on the same area of land returned over several years in order to track a particular phenomenon, such as deforestation or pollution. The future of LANDSAT has been in question so often that some researchers have been hesitant to invest in data and software without knowing if LANDSAT would continue to operate for the next several years. At least one program, at the Department of Agriculture, is waiting until LANDSAT 6 is launched to begin studying the data, rather than face an interruption when LANDSAT 5 ceases operation.[39] A data gap between the existing LANDSAT's and LANDSAT 6 would also discourage some users from investing in LANDSAT data. The potential lack of data continuity thus has complicated EOSAT's efforts to broaden the market, a necessary step for successful private operation of the system.

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[36] Eosat. Landsat Data Users Notes. May 1989, p. 5.

[37] Elkington, John and Jonathan Shopley. The Shrinking Planet: U.S. Information Technology and Sustainable Development. World Resources Institute. June 1983, p. 27.

[38] Rohrer and Smith, p. 7.

[39] USDA National Agricultural Statistics Service is planning to use Landsat 6 data. Richard McArdle, telephone conversation July 10, 1989.

Other U.S. Remote Sensing Satellites

While the NOAA weather satellites and LANDSAT are in the forefront of remote sensing satellites which monitor agricultural and environmental conditions, other satellites also contribute, including Nimbus-7 and Seasat. Additional satellites or platforms are planned for the future.

NIMBUS-7

NASA launched Nimbus-7 in October 1978 and it continued operations through mid-1986. The last in a series of seven satellites designed for meteorology and oceanography, Nimbus-7 made a unique contribution to remote sensing measurements of ocean productivity with an instrument called the Coastal Zone Color Scanner (CZCS). The CZCS data identified regions where there is a high concentration of phytoplankton in the Atlantic and North Sea. The concentration of phytoplankton correlates closely with fish life concentrations. When NASA conveyed information on phytoplankton concentrations to fishermen on the West Coast, they reported a higher catch of albacore along the boundaries of the phytoplankton concentrations.[40] NASA is continuing to use CZCS data to study and improve their capability to estimate phytoplankton productivity and ocean productivity.[41]

Nimbus-7 also monitored pollution problems, including ozone concentrations in the Earth's upper atmosphere, warming and cooling trends, and pollution in the oceans. The Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) collected data which NASA used to examine the Antarctic Ozone hole.[42]

EOSAT is considering putting an improved version of the CZCS, called Sea WiFS (Sea-viewing, Wide-Field-of-View Sensor), on LANDSAT 6. NASA and EOSAT had agreed to share the cost of the sensor. NASA then would distribute the data free of charge to researchers, and develop a data archive. EOSAT would sell data to commercial buyers.[43] The future of this program is in doubt, however, because of cost overruns and lack of sufficient funds.

SEASAT

NASA developed Seasat, the first satellite dedicated to ocean remote sensing, and launched it in 1976. The satellite failed 106 days after launch. It carried five instruments: (1) a microwave scatterometer, (2) a scanning multichannel microwave radiometer, (3) a synthetic aperture radar, (4) a radar altimeter, and (5) a visible and infrared radiometer. In addition to NASA, seven government agencies and many public and private institutions participated in analyzing the research. Despite the early failure, NASA felt the data produced by Seasat was promising, and identified four areas to which the data could be applied: marine condition forecasts, off-

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[40] Perry, Mary Jane. Assessing marine primary production from space. Bioscience, v. 36, July/August 1986, p. 464

[41] NASA. ESAD. The Program and Plans for FY 1988–1989–1990. September 1988, p. 54.

[42] Testimony of Dr. Robert T. Watson, Office of Space Science and Applications, NASA, before the U.S. House of Representatives, Committee on Interior and Insular Affairs, September 27, 1988, p. 20.

[43] NASA. ESAD. September 1988, p. 63.

shore resource exploration, commercial fishing, and marine transportation.[44]

SHUTTLE IMAGING RADAR

The space shuttle has carried two shuttle imaging radar sensors, SIR-A in 1982 and SIR-B, an advanced version of SIR-A, in 1984. During the flight of SIR-B, 200 scientists from 13 countries were involved in using the data to study geology, hydrology, archeology and vegetation. SIR's radar can penetrate clouds and vegetation to gather data on the ground below.[45] NASA plans to fly SIR-C on a future shuttle mission.

Future U.S. Remote Sensing Satellites

Two future remote sensing projects are under construction and are scheduled for launch in 1991 (TOPEX/Poseidon and UARS). As discussed earlier, NASA is proposing a major program called Mission to Planet Earth for the 1990's and beyond which could include a vast array of sensors on large platforms to make a comprehensive study of the Earth and its environment.

TOPEX/POSEIDON

NASA's Topography Experiment for Ocean Circulation (TOPEX) is being planned in conjunction with France's Poseidon mission. NASA will provide the satellite and TOPEX sensors and the French space agency, CNES, will provide Poseidon sensors and a launch on the Ariane launch vehicle (currently scheduled for 1991). The satellite will study sea currents, oceanic circulation and the movement of heat in the ocean using radar altimeters. One objective of the TOPEX program is to provide a synoptic, global description of the ocean's circulation, including its interaction with the atmosphere and relationship to climate change, in order to improve climate prediction.[46]

UPPER ATMOSPHERE RESEARCH SATELLITE (UARS)

The Upper Atmosphere Research Satellite (UARS) will gather data on the chemistry and dynamics of the stratosphere and upper mesosphere, and on the role of solar radiation and dynamics of ozone in the upper atmosphere. The program was begun in part to respond to concern about depletion of ozone in the stratosphere. NASA plans to launch UARS in 1991.[47]

MISSION TO PLANET EARTH—THE EARTH OBSERVING SYSTEM

As noted above, NASA is planning a coordinated interagency and international effort to study the Earth as a system in Mission to Planet Earth. NASA's conceptual plan includes a large number of platforms and other spacecraft, comprised of four components:

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[44] For more information, see: United States Civilian Space Programs, Vol. II, pp. 296–304.
[45] Covault, Craig. Challenger Crew Obtains Significant Science Data. Aviation Week and Space Technology, October 15, 1989, pp. 17–18.
[46] NASA. Flight Project Data Book, 1989. March 1989, p. 45.
[47] Ibid., p. 72.

(1) polar orbiting platforms, also known as the Earth Observing System: two would be provided by the United States, one by the European Space Agency (ESA), and one by Japan;

(2) five geostationary platforms: the United States would provide three, ESA one, and Japan one;

(3) instruments attached to the U.S./International Space Station Freedom that would collect data in low Earth orbit; and

(4) individual free-flying satellites: a Tropical Rainfall Mapping Mission, a Geopotential Research Mission, and a Magnetic Field Explorer.[48]

Depending on how many platforms were approved, the program would cost the United States alone between $15 and $30 billion over 15 to 20 years.[49]

Currently, only the first U.S. polar platform is undergoing detailed planning in NASA, which expects to request funding for it in fiscal year 1991. Called EOS–A, it is being planned for a 1996 launch; the second platform, EOS–B, could be launched in 1998. Each platform is being designed for an operational life of 15 years. NASA plans for the first platform to carry 19 instruments to view and gather data about the Earth. The second platform would carry additional instruments, including a large imaging radar. The spacecraft would gather data on the composition of the atmosphere, temperature, and weather conditions around the world.[50]

Japan and the European Space Agency (ESA) are developing similar platforms which will carry their sensors plus U.S. instruments, and are currently planned for launches in 1998 and 1997, respectively. Japan has proposed several instruments to be carried on EOS–A and B and scientists from around the world have met with NASA to plan the development and use of the instruments.

Because the space platforms will carry so many complex instruments, they are expected to gather about 1,000 times the amount of data collected by current spacecraft. This will require a new data processing system, which is being called EOS Data and Information System (EOSDIS). NASA is soliciting bids on the data system.[51]

Among the instruments under development or in planning for EOS–A are: [52]

(1) The moderate-resolution imaging spectrometer (MODIS), designed to take a broad look (resolution of 0.5 kilometers) at the atmosphere, ocean and land in visible and infrared bands. It will measure the temperature of the atmosphere and ocean, ocean productivity, land surface composition and biological activity, and cloud properties.

(2) The high-resolution imaging spectrometer (HIRIS), with 30 meter resolution and 196 spectral bands to provide very de-

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[48] U.S. Congress. Senate. Committee on Commerce, Science and Transportation. Mission to Planet Earth. Hearing, 101st Cong., 1st sess. March 8, 1989, pp. 28–30. Testimony of Dr. Leonard Fisk.

[49] Covault, Craig. Major Space Effort Mobilized to Blunt Environmental Threat. Aviation Week and Space Technology, March 13, 1989, p. 36.

[50] New Earth Observing Platforms to Study Water, Biology. Aviation Week and Space Technology. March 13, 1989, p. 46.

[51] Ibid., pp. 46–47.

[52] Compiled from: Aviation Week and Space Technology. March 13, 1989, pp. 49–50; NASA. Earth Observing System, 1989 Reference Handbook, pp. 12–26; and NASA. From Pattern to Process: The Strategy of the Earth Observing System. EOS Science Steering Committee Report. Vol. II, pp. 18–19.

tailed geological, biological and physical information on fairly small areas. The primary sensor will be a very sensitive reflecting optical telescope which could measure crop stress due to drought or pollution. HIRIS will also measure land surface composition and biological activity, biological activity in oceans and lakes, and cloud properties.

(3) A geoscience laser ranging system (GLRS), which will provide information on the Earth's crustal movements by bouncing laser beams off ground-based reflectors. It will also collect data on ice sheets, glaciers, and cloud tops.

(4) An atmospheric infrared sounder (AIRS), which will measure atmospheric temperature and moisture at different altitudes.

(5) A radar altimeter, which will measure ocean circulation and waves and ocean surface winds and will be similar to TOPEX, described below.

(6) An advanced microwave scanning micrometer, proposed by Japan, to measure atmospheric water vapor, sea surface temperature, and sea surface wind.

(7) A laser atmospheric wind sounder (LAWS), which is under study to take wind measurements in the troposphere. NASA is considering putting LAWS on the Japanese polar platform.

Other instruments include a passive microwave system to measure rainfall, a microwave sounder to measure temperature, and a radar scatterometer to measure water evaporation from the ocean.

EOS–B may carry a synthetic aperture radar (SAR) that would provide data on land, vegetation, ice and oceans, including measuring surface soil moisture and wetlands areas. The SAR would have a varying resolution, depending on what mode it is used in, between 20 to 30 meters and 200 to 500 meters.

Other Countries' Satellite Systems

Countries in Europe, Japan, India, China, and the Soviet Union operate weather, land remote sensing, and other satellites which gather data to monitor the environment and food security.

WEATHER SATELLITES

Japan, the European Space Agency (ESA), and India each operate geostationary weather satellites and contribute weather data to the World Weather Watch (WWW) and the Global Atmospheric Research Program (GARP) of the World Meteorological Organization (WMO). These three satellites plus the two U.S. geostationary weather satellites are placed in geostationary orbit at intervals to provide full coverage of the Earth (except for areas around the North and South Poles which a geostationary satellite cannot view).

The Japanese satellite, GMS (also known as Himawari), is located at 140 degrees east and views the western Pacific. Japan launched GMS–1 in 1977, GMS–2 in 1981, GMS–3 in 1984, and GMS–4 in 1989.

METEOSAT, developed by ESA, is located at 0 degrees longitude and covers Europe and Africa. ESA launched METEOSAT–1 in

1977, METEOSAT-2 in 1981, and an advanced version of the satellite, called MOP, in 1989. In 1987, 16 European nations formed Eumetsat to take over all METEOSAT operations.

The Indian satellite, INSAT, is located at 72 degrees east and covers regions in Africa and Asia. INSAT 1A was launched in 1982, and INSAT 1B in 1983. INSAT 1A failed soon after launch, prompting the early launch of INSAT 1B, which, after early difficulties, has operated successfully. INSAT 1C is awaiting launch.

The Soviet Union has discussed launching a geostationary weather satellite, but none has been launched yet. It does operate a polar-orbiting weather satellite system, METEOR, and contributes some data to the WWW. A Soviet satellite designated Cosmos 1870 operated between July 1987 and July 1989 and carried radar which gathered data on hydrology, agriculture and the environment, including some weather data.[53]

China launched its first polar orbiting weather satellite in 1988.

JAPAN'S OCEAN SENSING SATELLITES

Japan launched its Marine Observation Satellite (MOS-1) in 1987. MOS gathers data over the land as well as the ocean. It carries a multispectral electronic self-scanning radiometer with 50 meter resolution. The sensor has four spectral bands, including both visible and thermal infrared regions. A second satellite, MOS-2, is planned for launch in 1990.[54]

SPOT—FRANCE'S LAND REMOTE SENSING SATELLITE

The French space agency, CNES, developed the SPOT remote sensing satellite and ground system. A private company, SPOT Image, was created to operate the system and market the data. CNES owns a 39-percent share of SPOT Image. Other French Government agencies own 20 percent, and European aerospace industry and banks own the remainder.

SPOT was designed as a commercial system, and each generation of satellites can be modified to include capabilities designed specifically to meet the customers' needs. SPOT Image, with the backing of the French Government, has made a commitment to an ongoing satellite program and has not faced funding problems of the magnitude of those faced by LANDSAT.

SPOT-1 was launched in February 1986; SPOT-2 is scheduled for launch in 1989. France has begun development of SPOT-3 and SPOT-4, thus ensuring that the system will operate through the 1990's. SPOT's carry a high resolution visible (HRV) sensor, which is a "pushbroom" linear array of detectors that scan electronically, with no mechanical or moving parts. The advantages of the HRV include increased resolution and minimal distortion. SPOT has 20 meter resolution in color and 10 meter in black and white. SPOT also is capable of stereo imaging, or the ability to see the same feature from different angles.

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[53] U.S. Senate. Committee on Commerce, Science and Transportation. Soviet Space Programs: 1981-87, Part 2. April 1989, p. 416.

[54] Turnill, Reginald, ed. Jane's Spaceflight Directory, 1988-89, pp. 41-42.

NASA has a special agreement with CNES to receive a certain amount of SPOT data at a reduced price, agreeing to use the data only for research.[55]

Satellite Interaction—The User's Perspective

As may be self-evident from the above descriptions, different satellites produce data suitable for diverse purposes. Some scientists choose to use data from one specific sensor, while others use and combine data from several sensors. Because the science and study of remote sensing data for monitoring crops and the environment is always developing, there may be no definitive designation of which data is best for which purpose. However, anecdotal information about how the data has been used provides an outline for its usefulness.

LANDSAT and SPOT: Competitive or Complementary?

From a technological point of view, SPOT and LANDSAT are complementary. Each satellite has different capabilities. LANDSAT has more spectral bands and SPOT has higher resolution. LANDSAT has a thermal band and SPOT has stereoscopic imaging. SPOT and LANDSAT data have traditionally sold at roughly comparable prices and cost has not been a major factor when a customer decides which data to buy.

However, given the fact that data are getting increasingly expensive and researchers often have limited funding, many researchers cannot buy all of the data that they want from each satellite. Thus, the two systems may end up competing economically. From a competitive point of view, LANDSAT has unique technical features, primarily its many spectral bands, and an extensive archive of data, dating back to 1972. The LANDSAT system operates continuously, returning data over all of the Earth. The SPOT system is turned on primarily to gather specific scenes for customers, and does not have, and will not develop, extensive archives. SPOT also has unique technical features, 10 meter resolution in black and white and stereoscopic imaging, and has avoided the uncertainty about data continuity that has plagued LANDSAT.

SOVIET REMOTE SENSING DATA [56]

Two Soviet organizations, Soyuzkarta and Glavkosmos, market remote sensing data from Soviet satellites and from their space sta-

[55] NASA. ESAD. May 1987, p. 78.
[56] Smith, Marcia S. Soviet Space Commercialization Activities. CRS Rept. No. 88-473 SPR. July 6, 1988, pp. 3-4.

tion. Some Soviet remote sensing satellites are launched specifically to obtain data over a region specified by the customer. The spacecraft remains in orbit for 2 weeks and returns the exposed film to the ground in a capsule for processing. The resulting photographs have a resolution of 5 meters. The Soviet Union has also launched a series of ocean satellites, called Okean-O, which carry side-looking radar and transmit data digitally directly to ground stations in the Soviet Union. The Soviet Union has launched LANDSAT-type satellites, but little is known of the data they produce.[57]

FUTURE REMOTE SENSING SATELLITES

ESA Remote Sensing Satellite-1

The European Space Agency is developing a remote sensing satellite (ERS-1) to gather data on the oceans and ice. It will carry a synthetic aperture radar, a radar altimeter, and an along-track scanning radiometer. ESA plans to launch the satellite in 1990. The synthetic aperture radar will gather data on wind fields, ocean waves, ice coverage, ocean surface temperatures, and return radar images of the Earth's surface with 30 meter resolution.[58]

Japan's Earth Resource's Satellite

Japan is also planning an earth resources satellite (JERS-1) to be launched in 1991. The satellite also will carry a synthetic aperture radar and an optical sensor package.[59] Japan plans to use the satellite for locating mineral and energy sources, managing agricultural and forestry resources, environmental monitoring, and land-use planning. Japan is also planning an Advanced Earth Observing Satellite (ADEOS) for 1994. Japan is looking for international participation on the spacecraft. The primary sensors will be an ocean color and temperature scanner and an advanced visible and near-infrared radiometer.

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[57] Soviet Space Programs: 1981-1987, Part 2, pp. 414-16.
[58] Turnill, Reginald, Ed. Jane's Spaceflight Directory, 1988-89, pp. 339-40.
[59] Ibid., p. 42.

SATELLITE SYSTEMS AND FOOD SECURITY: ISSUES

The critical need for satellite data to assess food security issues has been outlined in the preceding chapters. Since the earliest days of satellites, the United States has been the primary provider of satellite remote sensing data to the international community, although Europe, Japan, India, and the Soviet Union now also provide data to international organizations involved in food security problems. The central issue therefore is whether the United States remains committed to building and operating satellite systems to provide such data for domestic and international use, or if it will rely more heavily on foreign data in the future.

Existing Satellite Systems

WEATHER SATELLITES

The NOAA weather satellites and the LANDSAT series of spacecraft exist today, but their long term future is in doubt. While the utility of weather and LANDSAT data are rarely, if ever, questioned, funding for these programs is traditionally difficult to obtain.

Today, the United States has only one GOES satellite instead of the normal complement of two because of earlier budget-driven decisions on how many satellites to buy and when to have them launched. Another lengthy debate developed over whether one polar orbiting weather satellite would be sufficient instead of two. Unexpected satellite failures, as have happened several times in recent years in the weather satellite program, can create major difficulties for users of the data. The utility of weather satellite data for studying food security issues is not well recognized outside the food security community. Users within that community may take a more active role in clarifying their requirements and interacting with decision-makers during future debates over how many satellites are needed and when.

LANDSAT

The LANDSAT system has experienced tremendous vacillations in funding and policy throughout the past decade, beginning with the Carter administration decision to move the program out of NASA and into NOAA, with the eventual goal of turning it over to the private sector for operation. The Reagan administration's decision to accelerate the transfer to the private sector, and subsequent policy reversals concerning subsidies to the company selected for operating the system, cast LANDSAT into years of political turmoil. The Bush administration decision to assure Government backing of LANDSAT may be comforting to users of LANDSAT

data, but the question of where the money for the program will come from in future years is still uncertain.

With the transfer to the private sector of the LANDSAT system, prices for LANDSAT data have risen. Also, the price paid by foreign countries to operate LANDSAT receiving stations tripled (to $600,000 a year). The ability of the user community, especially in developing countries, to use LANDSAT data for topics such as food security thus can be adversely affected by U.S. policy decisions.

Many special interest groups have stated their need for LANDSAT data, but the food security community has not been very visible in these debates. If LANDSAT data are required to study food security issues, as seems to be the case, a more active role may be necessary to garner support for the programs.[60]

Future Satellite Systems

MISSION TO PLANET EARTH

NASA is planning several satellites in the future that would produce data relevant to global environmental concerns, including food security. Perhaps the most visible of these is Mission to Planet Earth (MTPE), a 15–20 year program that, if approved, would involve both satellite and Earth-based sensors.

As with the existing systems, the major issue for MTPE is funding, although program management is at least as important. The U.S. part of the program is estimated at $15–30 billion over the life of the program. It is essential to have international participation in the program, and other countries will be contributing their own hardware and services to the effort.

Satellites like LANDSAT and NOAA study specific aspects of Earth. MTPE would study the entire planet, as a system, to see how different natural events and human activities affect each other. NASA has defined the satellite segment of MTPE, beginning with the Earth Observing System which is expected to be requested as part of NASA's fiscal year 1991 budget. This is only the first component of the planned system, however; eventually, MTPE would include not only EOS platforms in polar orbit (two U.S. platforms, one from Japan and one from Europe), but free-flying satellites and instruments attached to the U.S./International Space Station Freedom in low Earth orbit, and other satellites in geostationary orbit. An integral part of MTPE is the data collection, dissemination and storage system. Using the flood of data expected from the MTPE satellites and associated equipment on Earth is often described as "drinking from a fire hose."

The United States already is leading the way in planning MTPE, both within the U.S. Government and internationally. Coordination in both these arenas will be a major task. In the United States, several Government agencies—including NASA, NOAA, USGS, and

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[60] Private sector and other proponents of using weather satellite and other advanced information technology applications for agricultural and meteorological assessments have lobbied Congress for the establishment of a national agricultural weather information system which would have both monitoring and resource management responsibilities. See U.S. Congress. House. Committee on Agriculture. National Agricultural Weather Information System Act of 1989. House Report No. 101–14, Hearings on H.R. 1880, 101st Cong., 1st Sess., May 3, 1989. Washington, U.S. Govt. Print. Off., 1989.

NSF—are expected to play large roles in MTPE, but the only coordinating mechanism today is the Committee on Earth Sciences in the Office of Science and Technology Policy (Executive Office of the President). Some space program supporters want NASA to take the lead role for all MTPE activities, but NASA is reticent to take on the task both because of funding concerns, and because it has no authority to direct other Government agencies to perform specified tasks. Internationally, the success of the program will be dependent on the involvement of virtually every country in the world, either in providing satellite systems or ground data. Discussions already are underway in the International Council of Scientific Unions concerning its International Geosphere-Biosphere Program which is closely related to MTPE, and NASA has begun discussions with other space agencies regarding cooperation in providing satellite systems both as part of the U.S./International Space Station Freedom Program, and in other forums. The coordination process has only begun, however, and will have to be maintained over the lifetime of the program.

The questions for MTPE, then, are whether budgetary constraints will allow a U.S. commitment to conduct a 15–20 year program at a cost of $15–30 billion, and to provide leadership to the international community. If so, what agency will bear the primary responsibility for carrying out MTPE? Many observers feel that the current decentralized approach, with coordination only through the Committee on Earth Sciences, would be insufficient to meet program objectives.

If the decision is made to go forward with MTPE, another question will be how to ensure that potential data users for specific disciplines, such as food security, are involved in planning for the system, both in terms of the instruments to be carried on the spacecraft and in analysis of the resulting data.

OTHER SATELLITES

The main components of Mission to Planet Earth are large platforms that would house many different sensors. The principle behind these platforms is that they could be serviced by astronauts, so that if an instrument malfunctioned, it could be replaced and the rest of the instruments would not be impacted. Changes in policy have all but eliminated the reality of servicing platforms in polar orbits, however, and some observers question whether large platforms are the preferred approach to obtaining remote sensing data.

In addition to the NOAA and GOES weather satellites, and LANDSAT, NASA is already planning several free-flying satellites that will provide data relevant to questions that will be addressed through Mission to Planet Earth. Among them are TOPEX and UARS. NASA also plans to fly instruments on the space shuttle (although the shuttle can only remain in orbit for short periods of time).

Specialized groups, like the food security community, may become involved in assessing the advantages and disadvantages of large platforms versus smaller free-flying satellites or shuttle experiments to meet specific needs. If smaller, perhaps single-pur-

pose, satellites could provide the requisite data, the food security community might benefit from finding a funding source for a satellite or satellites dedicated to their needs. The emergence of "Lightsats" (small, relatively inexpensive satellites that can be launched by small rockets or aircraft) as an alternative to large, expensive spacecraft is becoming more attractive to other groups involved in space science and applications.

Agency Capacity To Use Remote Sensing Data

USDA monitors supply and demand conditions globally, among other factors, in order to make decisions about food needs and availabilities as an input to preparation of the congressionally mandated report assessing food needs and availabilities. AID monitors drought and crop conditions and needs information about potential famines in order to carry out programs of emergency relief and disaster assistance. NOAA is responsible for both research and development and applications of satellite technology in drought and food emergency monitoring and forecasting.

A frequently cited concern with respect to both USDA and AID is the need for training field staff in techniques for assessing crop conditions and estimating supply and demand for food and agricultural products. USDA's agricultural attaches are viewed by some as primarily promoters of U.S. agricultural exports rather than information analysts. Similarly, AID's field staff are viewed as primarily trained in project administration rather than crop condition assessment or methods for analyzing food supply and demand. Some believe that enhanced training, including training in the use and interpretation of satellite data, and the opportunity to develop expertise in food supply and demand analysis in particular regions or individual countries would strengthen both USDA and AID's monitoring and forecasting capability.

USDA's capacity to monitor and forecast drought and food problems in Sub-Saharan Africa and other low-income regions is constrained by the small number of agricultural attaches in those parts of the world. There are only four posts in Sub-Saharan Africa with agricultural attaches—Cote d'Ivoire, Kenya, Nigeria, and South Africa—and the attaches posted to those countries also have responsibilities for monitoring and reporting on food and agricultural conditions in surrounding countries. For example, the attaché posted to the Cote d'Ivoire has responsibility for reporting on agricultural conditions in the Sahelian countries. Similarly, the attaché in Nairobi, Kenya reports on conditions in other east and central African countries. The agricultural attaché in Egypt has recently been assigned responsibility to monitor and report on agricultural conditions in Sudan, while the attaché in South Africa reports not only on South African food and agriculture, but also on developments in other southern African countries. Given that there are AID personnel in most of the countries in Sub-Saharan Africa affected by droughts, should USDA augment the number of attachés in the developing African countries or increase the frequency of reporting on agricultural conditions in those countries or should USDA rely instead on AID field staff for its information?

Alternatively, should AID rely on an expanded agricultural attaché reporting network rather than its own field staff?

The benefits in terms of improved monitoring and forecasting and more timely responses to food emergencies to be gained from advanced information technologies; that is, satellite imagery and computer processing of satellite data, depend on the capacity of the agencies to access and use the data. Both NOAA and USDA make use of high-speed computers and sophisticated spreadsheet or other analytical software in processing and analyzing satellite and surface data. AID relies primarily on NOAA rather than its own internal capability to process and analyze satellite data. Were AID to decide to develop its own internal capacity to use satellite data rather than to contract for it with other Government agencies, it likely would have to invest in both hardware and analytical software to provide itself with the requisite capacity. The role of training in developing operational capacity was discussed above. To a large extent this issue has been resolved by AID's contracting out the development and analysis of satellite data.

Interagency Coordination

The number of organizations both within U.S. Government agencies and across the Government raise issues of possible duplication of effort and the need for interagency coordination. There is already some overlap of work between USDA and AID in estimating food aid needs; there appears to be some duplication of effort between NOAA and USDA in relating surface weather information with satellite data and using these data to make crop condition assessments. However, USDA's use of satellite imagery for crop condition assessment (with input from NOAA) has focused primarily on countries that are major producers and traders of grains and oilseeds, while AID (with NOAA's help) has focused on crop conditions in the developing countries.

In the past, AID has relied heavily on USDA and NOAA for information on drought and food conditions. More recently, AID has been increasing its own capacity to monitor and forecast droughts and famines, mainly by introducing reporting from the field on food supply and demand conditions and by establishing the Famine Early Warning System (FEWS). Some believe it would be efficient for AID to rely primarily or exclusively on USDA and NOAA for its information on droughts and famines in developing countries. On the other hand, if AID's program responsibilities for emergency food relief or disaster assistance mean that it needs capacity to generate, as well as use, information on drought and famine, what does AID need to do to strengthen its monitoring and forecasting capacity?

The administration has taken a number of steps to improve interagency coordination. The most important appear to be AID's participation with USDA in the preparation, review and clearance of quarterly reports to Congress on food needs and availabilities and the establishment of an interagency task force on food needs analysis chaired by USDA. A major concern of some observers is the prospect that the current enthusiasm for interagency cooperation and coordination will dissipate if and when the food crisis in

Africa fades from public attention. Recently AID has reduced its financial support of the interagency food aid needs assessment process.

A related issue is the degree to which organizational units within USDA and AID coordinate their monitoring and forecasting activities. USDA has a formal process for reviewing and clearing commodity and country/region food and agricultural supply and demand estimates before they are made public. AID has less formal procedures for reviewing and clearing estimates, but it appears that the role of intra-agency coordination falls primarily to the Bureau of Food for Peace because of its program responsibility for food relief.

International Cooperation

There is, by most accounts, a fair amount of coordination in monitoring and forecasting work between U.S. Government representatives in the field, whether USDA or AID, and FAO field personnel. The United States and FAO share information and have worked to resolve technical differences over procedures for making estimates of food supply and demand. FAO and AID also share information and have made efforts to resolve differences.

Because the United States supplies such a large proportion of the global total of food aid, including nearly one-half of the emergency food aid provided to Sub-Saharan Africa in 1984–85, and because of the dominant role of the United States in world agriculture, there is near universal agreement that the United States needs to maintain a global food and agriculture information system. However, FAO is an important source of information on food needs for most other bilateral food aid donors and for the World Food Program. Conflicting U.S. and FAO estimates of food need would unnecessarily complicate the response of the international community to food emergencies. Sharing information and technologies and resolving technical differences over procedures for estimating food supply and demand should enhance the response of the international community to food emergencies.

Similar considerations apply to cooperation between U.S. Government agencies and both WMO and UNEP.

Building Developing Country Capability To Use Remote Sensing Data

Among the more serious obstacles to making improvements in monitoring and forecasting of agricultural and environmental conditions in the developing countries is the lack of capacity in those countries to collect and analyze data and report on their own food supply conditions and to make food needs assessments. More accurate data from the countries most likely to suffer from weather-related food shortages could lead to improvements in U.S. and international information on drought and famine and could also result in more timely and adequate responses to emergencies. Improving national systems for monitoring and forecasting droughts and famines would necessitate training, technical assistance and financial aid from both bilateral and multilateral sources. It would involve enhancing the capacity of developing countries to gather and ana-

lyze more conventional surface data on agriculture, including weather data, as well as developing their capacity to use advanced information technologies. A number of projects respond to this concern, but some question whether enough attention is being paid to providing developing countries with the hardware and analytical software needed to use remote sensing data effectively.

CONCLUSION

Ultimately, the question is what do those concerned with food security need to more effectively address the problem. If the need is for more or better data, then supporting new satellite (and associated Earth-based) projects would be required. If sufficient data are being generated today by satellite systems, but the problem is access to that data (for cost or bureaucratic reasons), other solutions will have to be sought.

Obtaining data to clarify the problem is a vital first step, and satellite remote sensing is an important tool in the process. The ability to forecast drought in Africa did not prevent starvation in Ethiopia, however. Ultimately, food security and environmental problems are political issues that can only be solved by governments.

LIST OF ABBREVIATIONS

[Parent agency or country indicated in parentheses]

ADEOS	Advanced Earth Observing Satellite (Japan)
AGRHYMET	Agriculture-Hydrology-Meteorology project (AID, France)
AgRISTARS	Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (USDA)
AID	Agency for International Development (U.S., also abbreviated USAID)
AISC	Assessment and Information Service Center (NOAA)
AMSU	Advanced Microwave Sounding Unit
ARS	Agricultural Research Service
ARTEMIS	Africa Real Time Environmental Monitoring using Imaging Satellites
ASCS	Agricultural Stabilization and Conservation Service (USDA)
ATS	Applications Technology Satellite (NASA)
AVHRR	Advanced Very High Resolution Radiometer (NOAA)
CIA	Central Intelligence Agency (U.S.)
CZCS	Coastal Zone Color Scanner (instrument on Nimbus-7 satellite)
DCS	Data Collection System
DMSP	Defense Meteorological Satellite Program (DOD)
DOD	Department of Defense (U.S.)
EC	European Community
ERBE	Earth Radiation Budget Experiment (NASA)
EOS	Earth Observing System (NASA)
ERS	Economic Research Service (USDA)
ERS-1	European Remote Sensing satellite (ESA)
ESA	European Space Agency
FAO	Food and Agriculture Organizations (United Nations)
FAS	Foreign Agricultural Service (USDA)
FCCAD	Foreign Crop Condition Assessment Division (FAS, USDA)
FEWS	Famine Early Warning System
FIFE	First ISLSCP Field Experiment

LIST OF ABBREVIATIONS—Continued

[Parent agency or country indicated in parentheses]

GARP	Global Atmospheric Research Program
GDPS	Global Data Processing System (WMO)
GEDES	Global Economic Data Exchange System (FAS, USDA)
GEMS	Global Environmental Monitoring System (UNEP)
GIEWS	Global Information and Early Warning System on food and agriculture (FAO)
GMS	Geostationary Meteorological Satellite (Japan)
GOES	Geostationary Operational Environmental Satellite (NOAA)
GOS	Global Observing System (WMO)
GRID	Global Resources Information Database (UNEP)
GTS	Global Telecommunications System (WMO)
HIRS	High Resolution Infrared Sounder
ICSU	International Council of Scientific Unions
INSAT	Indian weather/communications satellite
ISLSCP	International Satellite and Land Surface Climatology Program (WMO and interagency)
JERS	Japanese Earth Remote Sensing satellite
JWF	Joint Agricultural Weather Facility (Interagency)
LACIE	Large Area Crop Inventory Experiment
LANDSAT	U.S. privately operated land remote sensing satellite
MOS	Marine Observation Satellite (Japan)
METEOSAT	European meteorological satellite (ESA)
MSS	Multi-Spectral Scanner (instrument on Landsat)
MSU	Microwave Sounding Unit
MTPE	Mission to Planet Earth (U.S. interagency/international)
NASA	National Aeronautics and Space Administration (U.S.)
NASS	National Agricultural Statistical Service (USDA)
NESDIS	National Environmental Satellite, Data and Information service (NOAA)
Nimbus	U.S. weather satellite (NASA)
NOAA	National Oceanic and Atmospheric Administration (U.S.)
NSF	National Science Foundation (U.S.)
Poseidon	French ocean sensing experiment (in conjunction with TOPEX)
RDP	Research and Development Program (WMO)
SAR	Synthetic Aperture Radar
SBUV	Solar Backscatter Ultraviolet Experiment
SCS	Soil Conservation Service (USDA)

LIST OF ABBREVIATIONS—Continued

[Parent agency or country indicated in parentheses]

Seasat	U.S. ocean sensing satellite (NASA)
SEM	Space Environment Monitor
SIECA	Permanent Secretariat of the General Treaty on Central American Integration
SIR	Shuttle Imaging Radar (ocean sensing instrument on space shuttle)
SMS	Synchronous Meteorological Satellite (NASA)
SPOT	French land remote sensing satellite
SSU	Stratospheric Sounding Unit
TIROS	Television Infrared Observation Satellite (NASA)
TM	Thematic Mapper (instrument on Landsat)
TOPEX	Topography Experiment for Ocean Circulation (NASA, in conjunction with Poseidon)
TOVS	TIROS Operational Vertical Sounder
UARS	Upper Atmosphere Research Satellite (NASA)
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
USGS	United States Geological Survey (U.S. Department of the Interior)
VAS	VISSR Atmospheric Sounder
VISSR	Visible and Infrared Spin Scan Radiometer
WAOB	World Agricultural Outlook Board (USDA)
WCP	World Climate Programme (WMO)
WFP	World Food Program
WMO	World Meteorological Organization (United Nations)
WWW	World Weather Watch (WMO)

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